Community Based Demonstration Projects: Willamette Ecosystem Services Project (WESP) Implementation Plan

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Contents

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Glossary of Terms

Clients- EPA offices and Regions that are the direct beneficiaries of the products being developed through this research program
Stakeholders- Non-EPA government and non-government entities that will benefit from the products being developed through this research program
DSP- Decision Support Platform
ES- Ecosystem Services
ESA- Endangered Species Act
ESRP- Ecosystem Services Research Program
NCEA- National Center for Environmental Assessment
ORD - Office of Research and Development
TMDL- Total Maximum Daily Load
WED - Western Ecology Division
WESP- Willamette Ecosystem Services Project
WRB- Willamette River Basin
WESD- Willamette Ecosystem Services District

1. Introduction and Background

Ecosystem services are defined as those functions of ecosystems that support (directly or indirectly) human welfare. They occur at multiple scales, from climate regulation and carbon sequestration at a global scale, to flood protection, water quality regulation, and food and fiber production at regional and local scales. They are both directly (as in recreational opportunities) and indirectly (as in climate regulation) connected to human well-being.
(Adapted from Costanza, unpublished)

Society is only in the early stages of developing processes and methodologies to quantify and value ecosystem services. This has prevented full recognition of the benefits to human well-being provided by proposed regulations and policies. While today's technology and knowledge can reduce considerably the human impacts on ecosystems, they are unlikely to be deployed fully until ecosystem services cease to be perceived as free and limitless, and their full value is taken into account.

An important environmental problem for the EPA is control of point and non-point sources of pollution, whose impact on ecosystem services is difficult to assess due to problems of fate, transport and interactions among pollutants. For example, non-point sources of pollution that contribute to both agricultural runoff and greenhouse gas emissions, are difficult to control through traditional "end-of-pipe" regulatory actions. This is because non-point pollutants become intricately linked with ecosystems, which respond in a variety of ways to pollutants entering the soil, air and water.

Ecosystems can remove or sequester pollutants, thereby providing a cleansing service depending on the particular pollutant source and type. However, ecosystems that are disturbed, or are in various impaired states (i.e. overwhelmed by inputs of pollutants) may not provide those services that contribute to human well-being, and can actually add to adverse effects.

Furthermore, while we may know the technological cost of controlling pollutants in order to provide clean drinking water and clean air, but we do not really know the value of lost or existing ecosystem services which may perform the same functions more economically. Without this understanding we can neither realistically determine the cost of pollution control regulations, nor can we calculate the economic benefits of ecosystem services.

In response to the critical need to conduct innovative ecological research that provides the information and methods needed by decision makers to assess the benefits of ecosystem services to human well-being, and, in turn, to shape policy and management actions at multiple spatial and temporal scales; the EPA initiated the Ecosystems Services Research Program (ESRP, http://www.epa.gov/ecology/). The overall goal of the ESRP is to conduct new research to characterize ecosystem services and to present this information in decision-relevant contexts. Research will be organized around two types of foci: *ecosystem type* (for example, wetlands and coral reefs will be studied) and *geographic place* (five place-based studies are being initiated). Research themes cutting across these systems and places will include 1) monitoring, modeling and mapping; 2) future-scenario analysis and valuation of services; 3) impacts of reactive nitrogen; 4) relationships to human health; 5) development of appropriate decision support systems; and 6) education. This 5-year effort will require that EPA's ecological researchers develop new partnerships across disciplines (e.g., with economists and social scientists) and agencies. It will enable decisions that better account for the full value of ecosystem services, in their present condition and as they may be altered in the future. The work proposed here is intended to support this effort through the development of transferable approach and decision support platform (DSP) addressing a variety of ecosystem service metrics relevant to the Willamette Basin, Oregon.

A central theme of our research plan is that ecosystem services tend to be tightly linked, or "bundled", such that land use decisions targeted for one service may have far reaching positive or negative impacts on other services. Reflecting EPA's prevailing risk assessment paradigm since the early 1980s (NRC 1983; Norton et al. 1992), models typically have been used to assess single or narrow sets of endpoints. For example, risk assessments concerning water quality or air quality traditionally have been treated as isolated issues by distinct program offices within EPA. The EPA recently established the Ecosystem Services Research Program (ESRP) to help formulate methods and models that consider broader sets of endpoints (http://www.epa.gov/ecology/). Under this new paradigm, the ESRP aims to develop comprehensive risk assessments that quantify how multiple ecosystem services interact and respond in concert to environmental changes. A major goal is to assess how alternative climate and land use scenarios will simultaneously affect tradeoffs in food and fiber production, regulation of water quality and quantity, reduction of greenhouse gases, and other services. *Essential to this goal are highly integrated models that can be used to define policy and management strategies for entire ecosystems, not simply individual components of the ecosystem.*

2. Willamette Ecosystem Services Project (WESP)

The Willamette Basin in Oregon was selected as one of the five geographic places to conduct a place-based study. As a component of the larger ESRP, the Willamette Ecosystem Services Project (WESP) will receive broad direction in the form of five Long Term Goals from the ESRP component of the USEPA Office of Research and Development. Long-Term Goal 5 of EPA's ESRP is to "Complete five site-specific demonstration projects that illustrate how regional and local managers can proactively use alternative future scenarios to conserve and enhance ecosystem goods and services."

This Implementation Plan is designed to provide a framework for identifying research needs and directing resources to address the most pressing scientific questions surrounding ecosystem services in the Willamette Basin. While coordination among components of the ESRP is ongoing and considerable, the focus of this document is specifically the implementation of WESP research following the broad directions outlined in the WESP Research Plan (Landers et al., 2008). We intend WESP to be an intensive, interdisciplinary, ecosystem services oriented project that focuses on priority ecosystems and which is grounded in the reality of producing models and decision tools that will be used by decision makers at multiple organizational levels, including state and federal agencies mandated to manage environmental resources, as well as local watershed councils and non-governmental organizations with interests in improved ecosystem function. This information will help shape the latter stages of the project and will help to refine the ultimate tools that will be produced.

Background of Willamette River Basin

The Willamette River (**Figure 1**) is the 13th largest river in the United States, and the 29,727 km^2 basin supports a mosaic of agricultural, timber and recreational resources as well as several growing urban centers and their water supplies. The Willamette River Basin (WRB) has a Mediterranean climate with dry summers and wet winters. The Willamette River drains the Coast Range on the west side of the basin, the Willamette Valley, and the Cascade Mountains to the east. Forests dominate the Coast Range and Cascade Mountains, and have historically been important sources of timber products. The valley is comprised of diversified agriculture, with a growing component of urban and suburban land.

Population in the WRB is concentrated in the four major urban centers of Portland, Salem, Corvallis and Eugene. City limits and Urban Growth Boundaries determine the geographic extent of high density development today and in the future. The estimate of population in July, 2009 in the ten counties whose areas are in part or entirely in the WRB was approximately 2,700,000. By 2040, the total population of these ten counties is projected to be 3,900,000. Increasing population is a major forcing variable or stressor on the WRB and the delivery of ecosystem services. The Willamette River Basin represents an excellent case study area in which there are diverse and highly valued resources providing numerous ecosystem services in its current state. These services may be significantly impacted by population growth, land use and management change, climate change, and other stressors. Thus, there are important regional needs to understand the current value and distribution of ecosystem services, how stressors affect ecosystem processes and the services they provide, and provide tools for regional decision-makers to evaluate alternative policies for the future. The project builds upon a strong foundation of previous research on landscape condition and projected future change in the basin (Hulse et al. 2002; Baker et al. 2004). Environmental issues in the WRB include national and regional concerns like global climate change and air pollution. but they also include local concerns like land use change, river conditions, fish and wildlife resources, agricultural practices, and timber production.

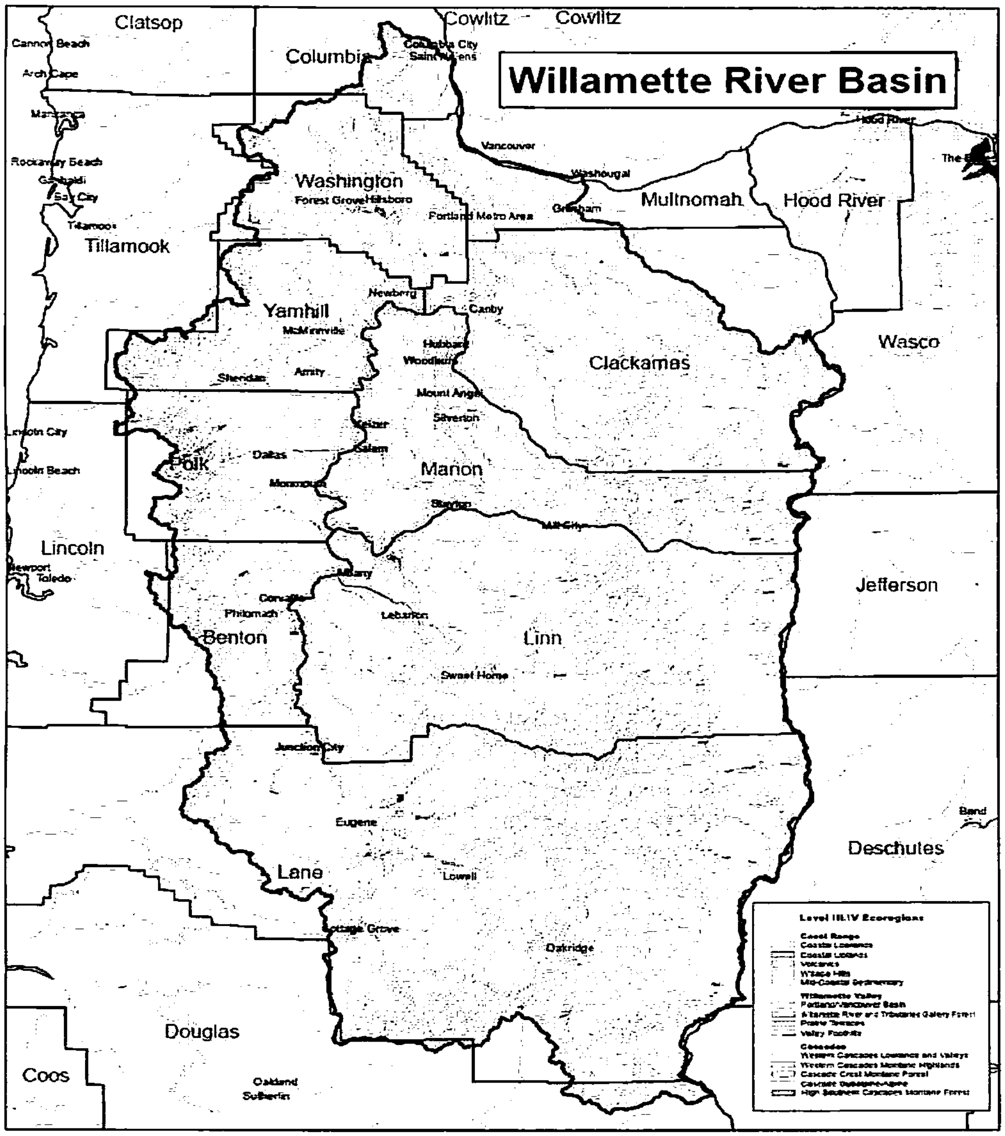


Figure 1. The Willamette River Basin showing major land use and land cover categories

The Willamette River network supports a wide variety of native and exotic fish species. Several fish species are listed under the Endangered Species Act (ESA) or are being considered for listing. Water temperature is a limiting factor for cold water fishery designated uses, and there are temperature TMDLs in place for multiple reaches of the Willamette and its tributaries (www.

deq.state.or.us/wq/TMDLs/willamette.htm). This has led to current and ongoing efforts to develop marketplaces for water cooling credits (www.willamettepartnership.org) through restoration of riparian forests and wetlands to provide this ecosystem service via increased shading and hyporheic flow, as well as other services such as improved aquatic habitat, flood control, and carbon sequestration.

Conceptual Model of Willamette River Basin Ecosystem Services

Figure 2 depicts decisions, stressors, ecosystem processes, ecosystems services, and values relevant to ecosystem service assessments in the WRB. While not meant to be an exhaustive list, this figure does show the major elements that have been identified by a variety of potential clients and stakeholders in the WRB as of priority concern. This conceptualization as a dynamic entity that will be modified through time as additional information becomes available and additional concerns are identified. This model provides an organizational framework for WESP's efforts at representing elements of ecosystem service provisioning and helps identify priority areas for research and implementation of decision tools for WESP.

Purpose of the WESP Implementation Plan

The purpose of this plan is to describe WESP's strategy for assessing ecosystem service under current and future conditions in the WRB that are responsive to client/stakeholder decision needs. Attempting to quantify human-relevant ecosystem services, valuing them across a spectrum of land uses and alternative future scenarios, and assessing the effects of stressors on the delivery of these services is an extremely complex endeavor. The methods to scale ecosystem services from research plots and transects to watersheds and regions, to financially evaluate ecosystem services, and to produce decision-support management tools have not been identified. In addition, sufficient resources do not exist to fully investigate all ecosystem services across the entire spectrum of stressors and drivers in the Willamette Basin. Therefore, project tasks and activities will evolve with time as new techniques, models, needs and collaborators from across ORD emerge.

Because of the evolutionary nature of the project, a flexible planning and prioritization framework is needed to implement research activities and to coordinate with participants from other divisions and laboratories within ORD. The purpose of this document is to present this flexible 'road map' for research managers and scientists to use in carrying out WESP research activities in order to meet the objectives of the project. In the first several sections of this implementation plan we provide a justification for narrowing the stressors and services of interest and describe the goals and scope of the WESP project (Sections 3 and 4), and a conceptual framework showing the linkages among various goals of the project (Section 5).

We next describe the general research approach taken by the WESP project (Section 6), and the decision support components of the project (Section 7). We will produce a decision support platform (DSP) focused on assessing production of bundled ecosystem services under future and alternative future conditions.

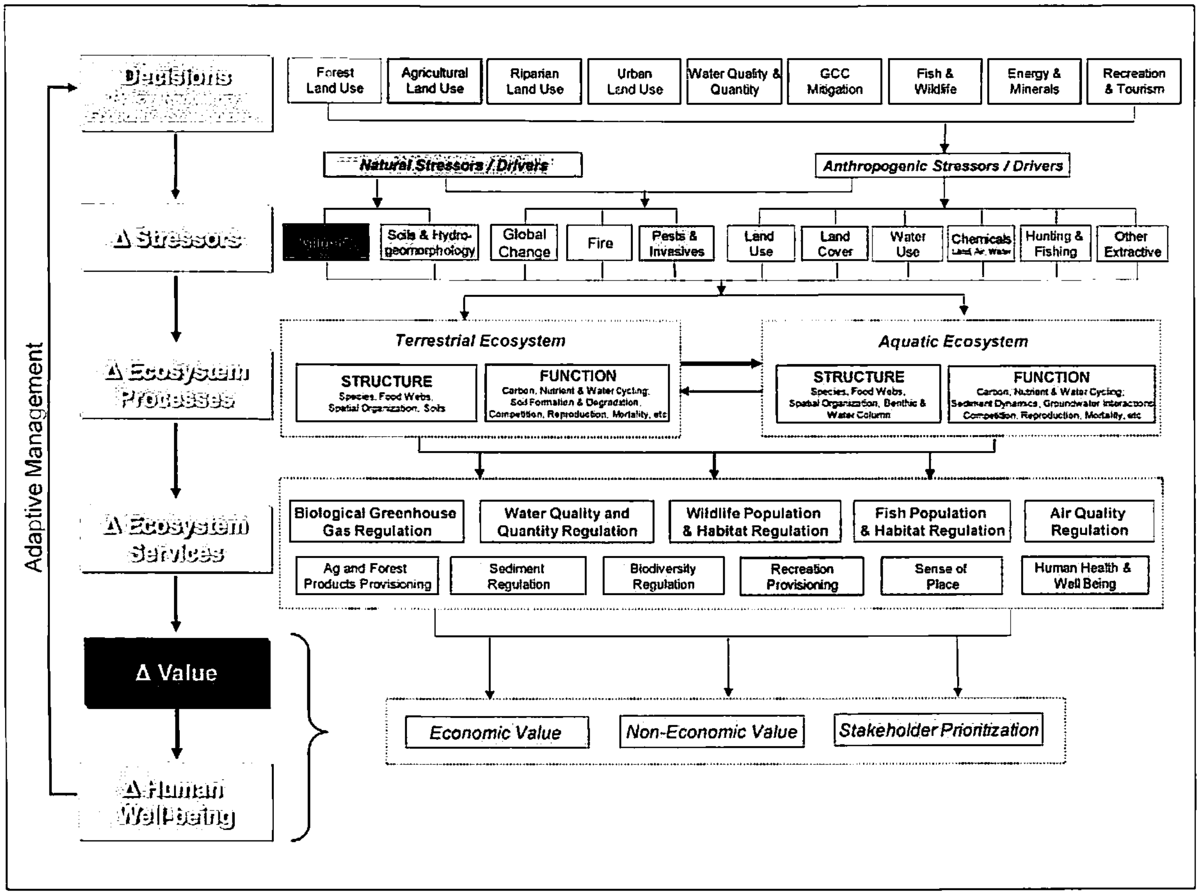


Figure 2. Willamette River Basin Conceptual Model

We will inform client and stakeholder-relevant management choices through the development of an integrative, flexible and extensible decision tool incorporating models of ecosystem service productions. Section 8 describes our plans for stakeholder involvement. Although at this time it is not possible to predict the ultimate scope of each task due to uncertainties and the evolutionary nature of the project, we provide a short narrative outline of the activities that we anticipate will be central to the completion of each task. Additional tasks may be identified as the project develops in coming years.

3. WESP Goals

Central to WESP is a focus on developing analytical tools that support land and water management decisions in the Basin aimed at assessing, protecting and enhancing ecosystem services and service bundles under current and alternative future conditions. This necessarily requires a number of important considerations: engagement of clients and stakeholders to understand and incorporate their needs and decision processes; access to or development of common datasets necessary to inform ecosystem service assessments; access to or development of state of the art models capturing important dimensions of ecosystem service representation; development of robust, flexible and extensible decision tools and frameworks allowing exploration of impacts of alternative management strategies on the production of ecosystem service bundles. Reflecting these needs, we propose the following overarching goals that will guide research activities within WESP:

1) Develop methodologies for characterizing and assessing selected ecosystem services in the WRB that:
    a. incorporate the best available science and knowledge;
    b. build on existing datasets available for the WRB:
    c. are spatially explicit:
    d. can be applied across multiple scales, e.g.. basin to project scales;
    e. can be applied to other geographic regions;
    f. can be incorporated into a decision-oriented analysis framework capable of assessing current and future trajectories of these services;
    g. reflect human valuations of these services.

2) Identify important current and potential future stressors on selected ecosystem services within the WRB.

3) Identify policy scenarios likely to affect these ecosystem services through mid-century.

4) In consultation with clients and stakeholders, develop alternative current and future scenarios that incorporate important stresses and policy options to examine selected ecosystem services at the basin scale.

5) Implement and test a flexible, extensible approach for decision support for understanding consequences of alternative management strategies on the delivery of these ecosystem services at multiple scales.

6) Improve existing approaches for modeling the response of these ecosystem services to natural and anthropogenic stressors.

7) Extend current scientific knowledge to address important knowledge gaps in understanding the ecosystem services of interest to WESP.

8) Identify additional ecosystem services of interest that could be studied should sufficient resources become available.

4. Project Scope

Because of the vast number of ecosystem services within the WRB and limited resources available, steps were taken to focus the overall scope of the project. **WESP will emphasize the development of a robust decision support framework and set of tools for assessing ecosystem service bundles under current and potential future conditions consistent with identified client and stakeholder needs.** We recognize the need for an approach that is flexible. robust, extensible. transferable to other geographic regions and applicable at multiple scales. We will demonstrate such an approach by initially focusing on small number of important services. Four criteria were used to identify those services of interest within the project. These criteria include *EPA regulatory authority*, *client needs*, *stakeholder interests*, and the *scientific expertise* available to address a particular service. Important clients are the EPA program offices (e.g., Office of Water, Office of Air) as well as EPA regional offices and state departments responsible for implementing EPA regulations. Prior work in the Willamette, coupled with a significant interest from a variety of stakeholder groups, has provided fertile opportunities for engaging stakeholders in this project. Stakeholders and possible collaborators include other government agencies, NGO's (e.g., Natural Capital Project and Willamette Partnership) and local groups (e.g., Watershed Councils). These are summarized in Figure 3. Although shifting priorities and resource constraints will influence the ultimate breadth and scope of the project, the four criteria listed above were used to identify the following five key services of interest to EPA in the WRB: ***Biological Greenhouse Gas Regulation, Water Quality and Quantity Regulation, Wildlife Populations and Habitat, Fish Populations and Habitat, and Air Quality Regulation.***

There was also a need to focus the list of stressors or drivers that are known to alter the provision of these services. Initially WESP will focus on two factors that have the greatest potential to significantly alter ecosystem services within the WRB: *Climate change and land use/land cover management and modification*. *Climate change* is widely recognized as being the premier environmental problem currently facing the globe. Rising temperatures, altered precipitation amounts and patterns, changes in accumulations and melting rates of alpine snow, and species shifts all have the potential to influence these ecosystem services within the WRB. *Land use/land cover management and modification* determines the extent to which services may be provided. Land use is often driven by population growth and economics, which are significant stressors to ecosystems within the WRB. Each of these stresses is, in effect, an independent variable, allowing us to examine how different manifestations of each variable influence the provision of ecosystem services across the extent of the WRB (dependent variables).

WESP is embedded in the larger ESRP and, as such, will relate to other parts of that national research program. The ESRP groups focusing on modeling, mapping, decision support framework (see section 8), education and outreach, nitrogen, and others, have activities and proposed products that can enhance work in WESP, and, correspondingly, research in WESP will provide methods, tools, and experiences with stakeholders that can inform other parts of ESRP.

5. WESP Conceptual Framework

The conceptual framework to guide the project is shown in **Figure 3**. The components of the framework lead to quantification of the five key ecosystem services Biological Greenhouse Gas Regulation, Water Quality and Quantity Regulation, Wildlife Populations and Habitat, Fish Populations and Habitat, and Air Quality Regulation. (bottom center). Each component addresses a specific goal indicated in parentheses below, while linked temporally and logistically to further achievement of the other goals. Through meetings and workshops with EPA clients and stakeholders in the WRB (top center), WESP scientists will first develop both spatial and temporal attributes which support each of the ecosystem services within the basin (Goal 1). These will include land use/ land cover types, underlying soil characteristics, climate characteristics, and other factors influencing the provisioning of each service. Current and future stressors will be identified for each ecosystem service (Goal 2). Equally important are the effects of various policies and how they may influence these landscape representations (Goal 3). Together, assessments of stressors and policy drivers will lead to the development of a series of possible scenarios of future change (Goal 4).

Outputs from the scenarios of future scenarios lead to the WESP landscape representation component (center of **Figure 3**), which will provide a structural framework for representing ecosystem services in the WRB. The landscape representation component will allow us to develop a decision framework (Goal 5) for assessing selected ecosystem services and service bundles, applied at different scales in the WRB. The decision framework will build on existing efforts in this area and will incorporate: 1) spatial depiction of relevant landscape attributes necessary to define the selected ecosystem services, 2) a set of models capable of assessing, using best available science, the production of these services for a given landscape configuration, 3) a capability for rapidly defining and generating a set of alternative future scenarios capturing client- and stakeholder-relevant decision choices and drivers of change, 4) a capability for portraying and visualizing trajectories of ecosystem service production under these alternative scenarios in client- and stakeholder-relevant ways, and 5) an ability to examine tradeoffs in bundled ecosystem service productions resulting from alternative decision choices.

The decision framework will allow an evaluation of the five key ecosystem services in the contexts of decision frameworks to meet client needs. We strive to provide a characterization of stressors and policy drivers on ecosystem services, and allow clients to explore tradeoffs in decision processes addressing production of bundled ecosystem services. This characterization may be qualitative, quantitative, or relative. Our modeling activities as indicated in Figure 3 lower right (Goal 6) and leveraging of ongoing fieldwork as indicated in lower left (Goal 7), will refine our landscape characterizations and lead to improved assessments of each of service analyzed. Implicit in accomplishing the characterization of these services and achieving Goal 5 is the need to provide an economic valuation of the ecosystem services of interest, and the economic loss associated with stressors and policy drivers. Expertise required to provide this valuation resides outside the current federal scientific staff at WED: therefore, WESP will need to partner with collaborators in order to accomplish this task. Finally, experience with use of the decision framework over time will help identify additional ecosystem services of interest that could be studied should sufficient resources become available (Goal 8).

Research within WESP will be conducted at the basin scale, and on smaller units that allow extrapolation to basin and larger scales. Specific areas to be studied are not yet determined, but will likely include the area including and surrounding the H.J. Andrews LTER site (forest-dominated landscape), the Calapooia watershed (mixed agricultural and forestry), and the McKenzie/Willamette Rivers confluence (mixed agriculture/forest/urban/riparian). These sites provide examples of where each of the key ecosystem services plays important roles in landscape management and where consideration of service bundles are important in determining cumulative benefits of two or more of these services, and where additional research from companion EPA projects is occurring that is relevant to WESP data and analysis needs.

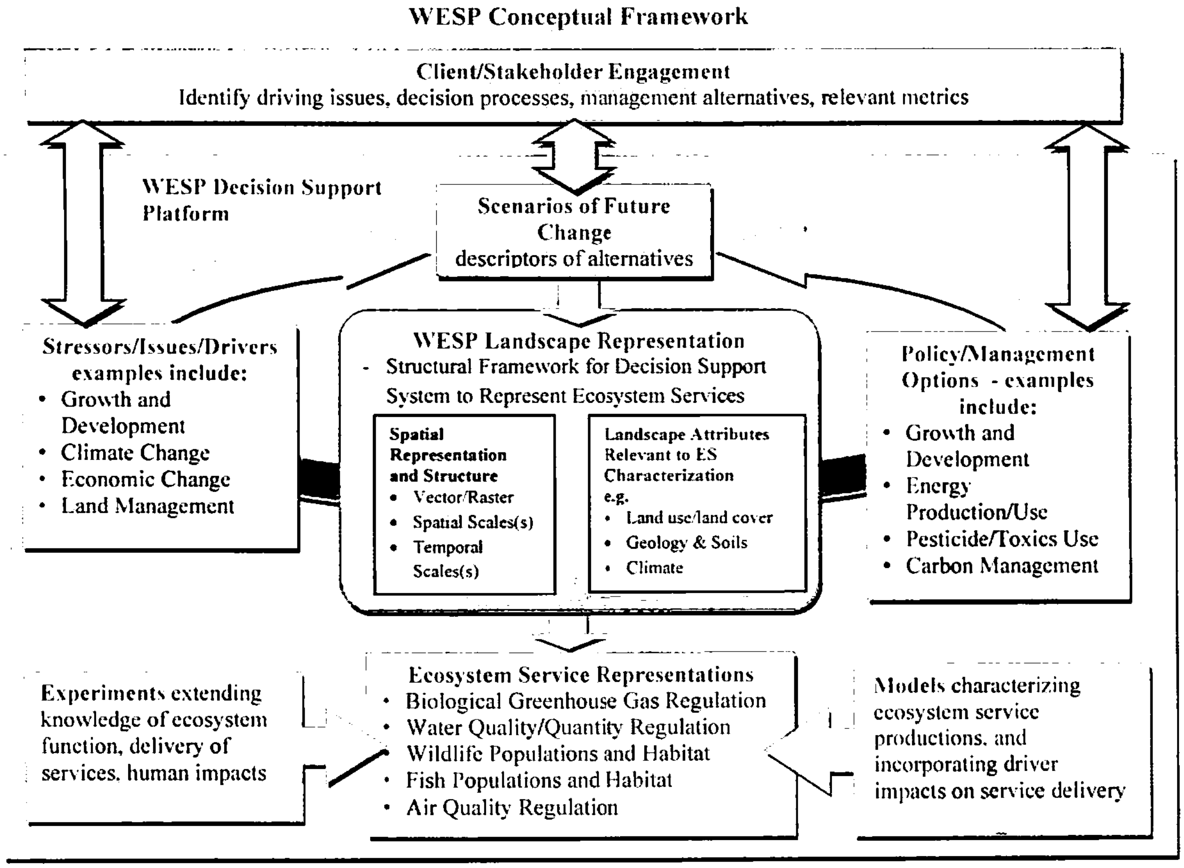


Figure 3. Conceptual Framework used to organize WESP Research and Outreach

6. General Research Approach

Our general research approach will focus on characterizing multiple ecosystem services through quantitative models and incorporating these models into a decision support framework relevant to identified clients and stakeholders in the Willamette basin. We will take a phased approach to this research (**Figure 4**). The first phase of the project will build on prior or current ecosystem services research for assessing current conditions and trends and developing datasets necessary for the models employed by the project. The second phase will focus on applying existing and new, relatively coarse models that target specific services (e.g. water quality and quantity) not adequately captured during Phase 1, working with clients and stakeholders to articulate alternative scenarios, and incorporating these into the WESP decision platform. The third phase will focus on continued refinement of models developed during Phases 1 and 2 and development of more detailed models where appropriate. Throughout this process identify and prioritize research tasks within WESP. For each of the five services - *Biological Greenhouse Gas Regulation, Water Quality and Quantity Regulation, Wildlife Populations and Habitat, Fish Populations and Habitat, and Air Quality Regulation* - the following steps will be followed:

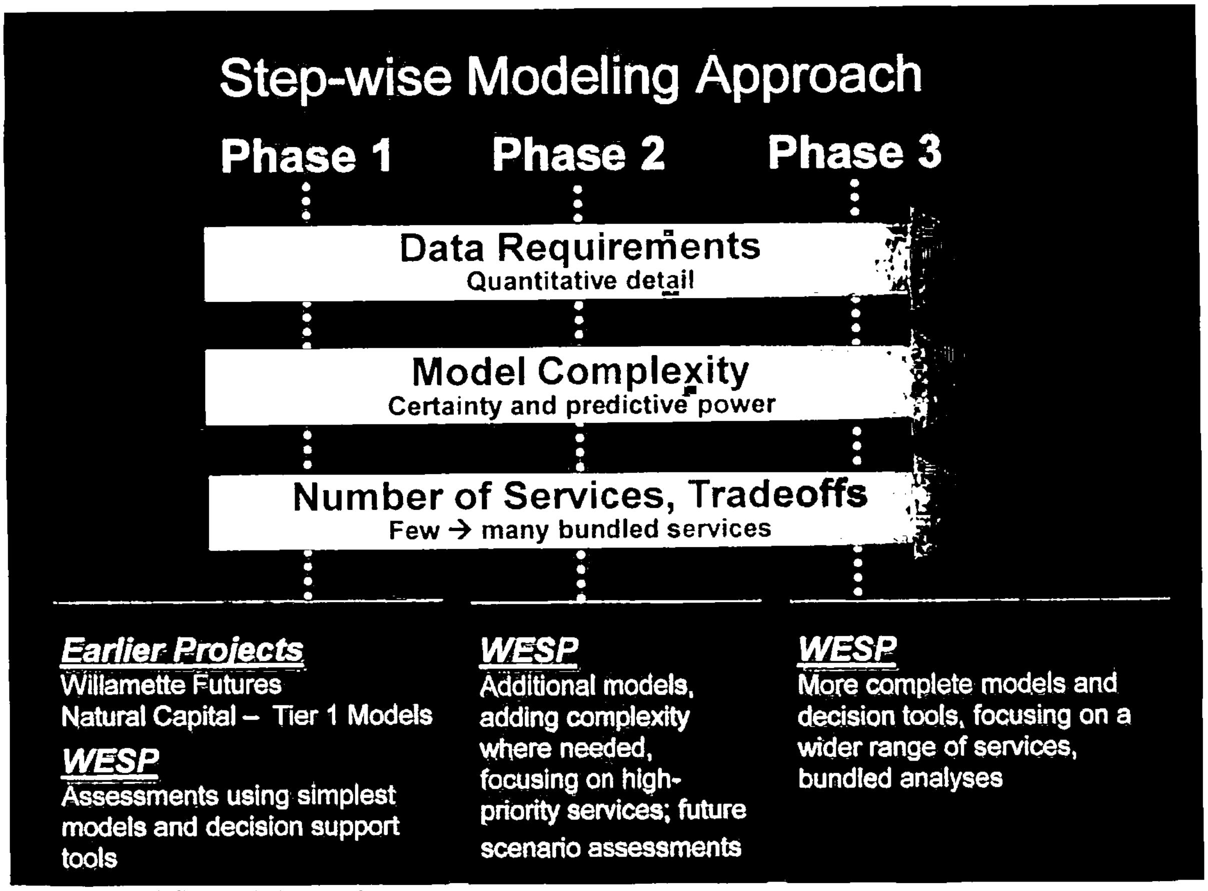


Figure 4. WESP Research Approach

1. ***Define and characterize the ecosystem service of interest.*** This step includes the background information and literature review that defines the service and identifies the important issues associated with the provisioning of this service in the Willamette Basin. It identifies the important service metrics or measures of this service, and most importantly establishes the relationships among this service and the EPA mission. Formulating the problem will involve identifying the dominant stressors of interest across the land types within the WRB.

Although stakeholder and client interaction is critical for all steps in this assessment framework, it is particularly important in this first step. The following questions will be addressed using published data and existing literature in evaluating each of the services addressed by WESP:

a. How is the service defined (assessment end point)?
b. What already is known and what are the metrics for this service (measurement end points)?
c. What is the relationship of the provisioning of this service to EPA mission?
d. Are there any important issues particularly unique to the provisioning of this service in the WRB?
e. What is the spatial extent of the service?

f. What are the dominant stresses or drivers that could threaten or enhance the provision of this service in the WRB?

2. ***Analyze stress-response data.*** This step includes an evaluation of the spatial and temporal distributions of the stressors and their co-occurrences with the provision of the ecosystem service. It also describes the relationships among the amounts of stressors and the magnitude of ecological effects on the service.

In this step, the following questions will guide the stress-response assessment:

a. What are the current and future impacts to ecosystem services?
b. What are the relationships among stressors, ecological processes, and resulting ecosystem services?
c. What are the major knowledge gaps?
d. Will the effect on one service influence the provision of another service?

3. ***Develop/adapt models relating ecosystem service provision to stressors and drivers.*** In this step, stress-response data gathered in step 2 will be synthesized using appropriate models. Our step-wise approach to modeling (**Figure 4**) will use progressively more detailed models to ultimately develop a systems approach for quantifying how multiple ecosystem services interact and respond in concert to environmental changes. Existing models will be reviewed and used/adapted where possible (see **Table 1**); new models will be developed where necessary. A common set of stressors and drivers will be identified and used to examine their effects on ecosystem services. In this step hypotheses will be formulated that will drive the modeling, mapping and empirical research in the project. Models will be developed and/or adapted that represent the processes that define the provision of the ecosystem service of interest, responsive to identified drivers, stressors, and decision choices. The models will be designed for integration within the WESP decision platform. The research supporting this effort will be determined in accordance with existing staff expertise and in association with collaborators also working in the WRB.

The following questions will be used to guide this step:

a. What is the likelihood of adverse effects occurring to each service as a result of each stress?
b. How can these effects be quantified, and with what certainty?
c. What additional research and modeling can improve our understanding of this service?
d. How will this research relate to the broader goals of WESP and the ESRP?
e. How can service be modeled and integrated into the decision platform?
f. How will the clients and stakeholders use this information?

4. ***Evaluate "bundled" ecosystem service response to alternative scenarios of land and resource management.*** Bundled ecosystem services refers to simultaneous evaluation of multiple services, generally to understand tradeoffs between services. This step involves incorporation of models developed in step 3 above into the WESP decision platform, articulating a set of drivers and stressors expressed in alternative future scenario depictions, and assessing provision of services and tradeoffs in service provision among alternative scenarios. We will work with WESP clients and stakeholders to define scenarios that are relevant to the decision choices they are facing.

The following questions will be used to guide this step:

a. What are appropriate representations of ecosystem service productions under alternative future scenarios?
b. What methods of representing ecosystem service bundles are of most value to clients and stakeholders?
c. What additional information is needed to help inform decision-making?
d. How can this approach to decision support be extended to other place-based studies?
e. How will the clients and stakeholders use this information?

Data Development

A number of challenges exist around acquisition, processing and managements of datasets needed for this project. The Willamette River Basin has a rich set of available spatial datasets relevant to informing ecosystem service assessments. Relevant datasets for selected ecosystem service endpoints are provided in **Table 1**. Known datasets available to the project include those listed in Appendix 1. These will be acquired, converted if necessary into a common map projection, and made available to project personnel. Additional datasets will be acquired as needed. We anticipate using only available datasets, except in the case of emerging carbon offset forestry issues for which new research is being conducted under EPA-WED's Carbon Offset Forestry project (research plan in preparation).

Envision, the WESP decision platform, requires a spatial representation of landscapes of interested to be developed that includes attributes required for ecosystem service assessments. To the degree possible, we will standardize on a geometry that provides reasonable representation of the ecosystem processes of interest while maintaining computability. We will explore several different geometries for representing this data, including hexagons and National Hydrological Dataset (NHD+) catchments, spanning multiple spatial scales. Additionally, we will utilize NHD+ representation of the stream network for those models that are stream based (e.g. hydrology, fish). Attributes to be included in the base coverages include, but are not limited to, land use/land cover, soils, climate, and topography, population/density, and road network.

In addition to these spatial data requirements, data describing the responses of ecosystem services to key stressors (e.g. climate, land use, population growth.) will be used to parameterize the ecological models that we will link to the *Envision* decision platform (see Section 7, Decision Support Components). **Figure 5** provides some examples of how the kinds of data described in Table 1 will be summarized in terms of *ecological response functions* for the purpose of model parameterization. Development of useful response functions requires a combination of monitoring data (e.g., long-term trends in water quality) and experimental data (e.g., dose-response data). The integration of disparate data sets through a systems modeling approach will address several key questions:

Table 1. Willamette Ecosystem Service Endpoints

Ecological Endpoints	Ecological Functions	Geospatial Data	Models	Primary Monitoring Data	Extent and resolution	People
Biological Greenhouse Gas regulation	Sequestration of carbon and nitrogen in plants and soils	LULC - GNN, CDL, etc.; soils - STATSGO, SSURGO; climate - PRISM, GCMs; topography - DEMs; hydrography - NHD+, RF1; Map of Potential Maximum C Sequestration on Forested Lands	Envision, using VELMA, InVEST, Harmon, Plantinga, …; Response Functions for Pot. Max. C Seq. as affected by GCC Drivers, and Forest Management	GHG fluxes from vegetation and soils; below ground biomass	Willamette River Basin, HJ Andrews LTER, ...	Bolte, McKane, Phillips, White, Johnson, Andersen, Rygiewicz, Beedlow, Ebert
Water quantity for drinking, fishing, boating, households, agriculture, irrigation, industry, power generation; flood protection Water quality for drinking, fishing, boating, households, agriculture, irrigation, industry, power generation	Storage and release in wetlands, soils, and plants Transformation and retention of water pollutants in wetlands, soils, and plants	LULC - GNN, CDL, etc.; soils - STATSGO, SSURGO; climate - PRISM, GCMs; topography - DEMs; hydrography - NHD+, RF1	Envision, using VELMA, WEAP, SWAT, SPARROW, MIMES, …	riverine riparian groundwater monitoring (intensive - Green Island, extensive - other sites	Willamette River Basin, HJ Andrews LTER, ...	Bolte, McKane, White Forshay, Faulkner
Wildlife populations and habitat	Develop diverse habitats for feeding, breeding, and dispersal	LULC - GNN, CDL, etc.	Envision, using HexSim-based matrix models, GAP, ESLI, …	Wildlife population data, habitat relationships	Willamette River Basin, HJ Andrews LTER, ...	Bolte, Schumaker White, Kepner

Fish populations and habitat	Develop diverse habitats for feeding, breeding, and dispersal	LULC - GNN, CDL, etc.; hydrography - NHD+, RF1	Envision, using FishMet, HSI, HexSim-based matrix models, ...	Fish population data, habitat relationships	Willamette River Basin, Calapooia, ...	Bolte, Rashleigh, Ebersole, White
Air quality regulation	Transformation and retention of air pollutants in plants and soils	LULC - NLCD, etc.: forests - FIA, etc.	i-Tree Vue (whole basin), i-Tree Eco (individual urban areas)		Willamette River Basin, individual cities	Bolte, Phillips

- What is the relationship between specific ecosystem services and the natural and anthropogenic stressors affecting them?
- How are the responses of ecosystem services linked as a result of interactions among processes disparate processes – e.g., hydrologic, biogeochemical and population processes?
- At what spatial and temporal scales do these responses and linkages need to be quantified to provide accurate and useful assessments of future changes in ecosystem services within the WRB?

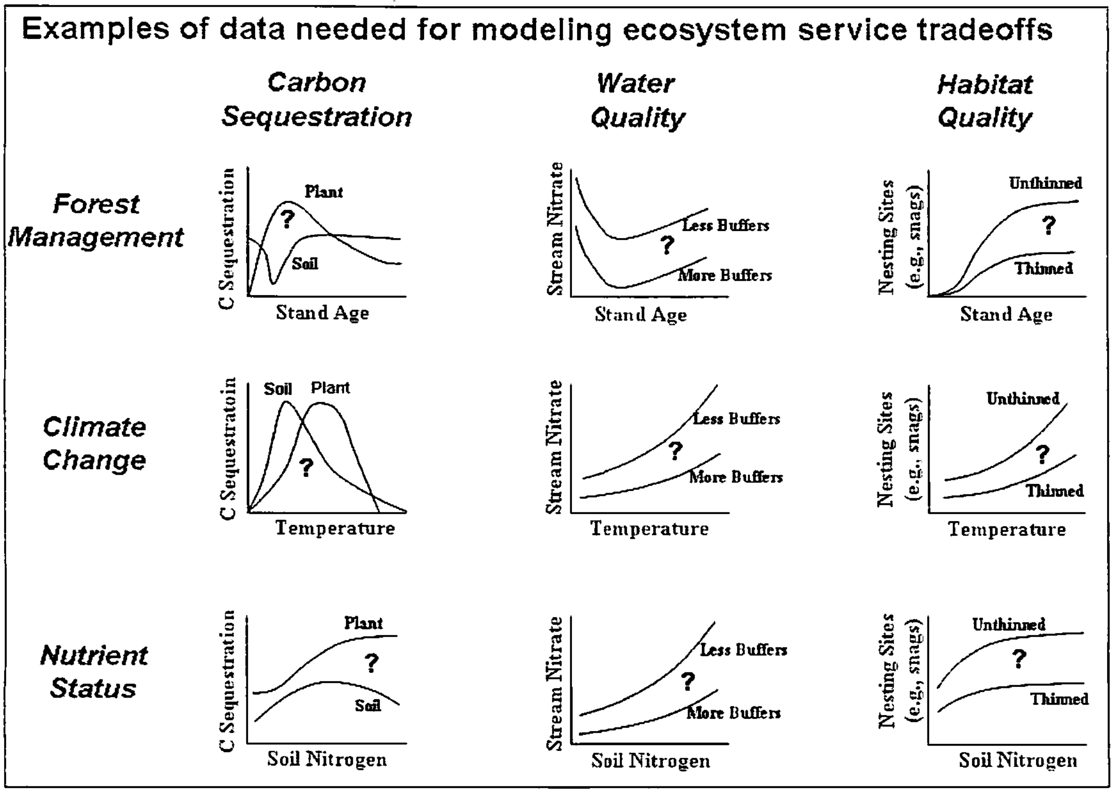


Figure 5. Ecological response functions describing effects of selected stressors (x axes) on multiple ecosystem services (y axes). Response functions for forest systems, depicted in this example, will be derived from available data and new research conducted under EPA-WED's Carbon Offset Forestry Project. Response functions for agricultural and riparian systems will be derived from available data and new research conducted by EPA's National Risk Management Research Laboratory Groundwater and Restoration Division in Ada, Oklahoma.

Integration and the WESP Decision Support Platform

Central to WESP's goals is the development of a robust decision support platform for representing ecosystem services and generating alternative futures assessments of those services. We have explored a number of options for decision frameworks and will utilize *Envision* (Bolte et al. 2007) as the WESP decision platform. *Envision* is an alternative future scenario toolset designed to generate suites of future scenarios that reflect possible decision choices and consequent effects on landscape change and provision of ecosystem services. These scenarios can include a variety of ecological, biophysical, social, and economic dimensions. *Envision* provides a multi-agent-based, decision choice-centric, spatially explicit alternative futures scenario generation and evaluation capability that is well suited to supporting ecosystem service assessments. Decision choices are explicitly represented in *Envision* as alternative scenarios that are interactively definable. Scenarios operationalize management choices, values and preferences of decision makers.

Key to the use of *Envision* is the inclusion of models of relevant ecosystem services of interests and the capability of representing influences of key driver, stressors and management choices on ecosystem service productions. The conceptual framework identifies a number of these relevant to the Willamette River Basin. WESP will initially focus on models representing the five key services identified above: *Biological Greenhouse Gas Regulation, Water Quality and Quantity Regulation, Wildlife Populations and Habitat, Fish Populations and Habitat, and Air Quality Regulation.* More complete descriptions of both the decision framework and models and modeling approaches to be employed by WESP are provided in below in Section 7: Decision Support Components.

The Willamette River Basin is notable for its diversity of land use/land cover (LU/LC) types. Because ecosystems services frequently span multiple LU/LC types, we plan on taking a comprehensive approach to considering and representing these types. Of particular interest are lands in forest, agriculture, large river riparian and wetlands classes. However, because many of the questions of interest to clients and stakeholders are related to impacts of growth and development on delivery of services, we will also represent urban and rural residential LU/LC classes in current and alternative future scenarios.

Our approach to integrating multiple ecosystem service representations will involve developing a WESP decision support platform (DSP) and associated set of tools for assessing selected ecosystem services and service bundles, applied at two scales in the Willamette River Basin. The DSP will incorporate: 1) spatial depiction of relevant landscape attributes necessary to define the selected ecosystem services, 2) a set of models capable of assessing, using best available science, the production of these services for a given landscape configuration, 3) a capability for rapidly defining and generating a set of alternative future scenarios capturing client- and stakeholder-relevant decision choices and drivers of change, 4) a capability for portraying and visualizing trajectories of ecosystem service production under these alternative scenarios in client- and stakeholder-relevant ways, and 5) an ability to examine tradeoffs in bundled ecosystem service productions resulting from alternative decision choices. We will utilize *Envision* to develop these prototypes at two scales: 1) a sub-basin scale analysis, focusing on forest ecosystem management, including the areas surrounding and including the H.J. Andrews Long Term Ecological Research site located in the McKenzie River watershed, and 2) an analysis of the entire Willamette River Basin. The first prototype will build on existing work in the H.J. Andrews LTER and will emphasize a relatively fine-scale depiction of the effects of alternative forest management practices on forest growth, carbon sequestration, greenhouse gases, water quality and quantity, and wildlife populations and habitat. The second, basin-wide prototype will emphasize coarser-scale depiction of carbon sequestration, water quality and quantity, and habitat and wildlife population processes across all land use types. Our goal with these prototypes is to develop initial assessments and representations of relevant ecosystem services and to incorporate these representations into a decision support framework capable of exploring tradeoffs in decision processes addressing production of bundled ecosystem services. Activities will focus on 1) developing appropriate spatial landscape representations of attributes necessary to assess ecosystem service productions, 2) implementation of a prototype DSP capable of representing these productions in a decision-oriented alternative futures framework, 3) incorporating into the DSP existing science-based models of ecosystem services relevant to the Willamette basin where available, and developing or enhancing models where necessary, and 4) conducting preliminary assessments of ecosystem service productions under current and alternative future scenarios to assess the utility of this approach at providing client-relevant decision tools. Specific DSP components to be developed under WESP are described in Section 7 below.

Criteria for Selection of Models for Inclusion in the WESP Decision Platform

Ecological models can provide a powerful means for predicting future conditions and analyzing responses to stressors. However, their use – and potential misuse – in conducting environmental assessments must be considered very carefully. Assessors in client offices are faced with a bewildering array of existing models that can be applied to a given question. On the other hand, model developers tend to focus mostly on scientific difficulties rather than client needs. We have identified five key criteria that scientists and Program Office personnel may find useful in selecting and developing ecological models to achieve EPA's assessment goals:

1) Statistical vs. process-based models? Both types of models are essential to EPA's assessment goals insofar as they present distinctly different strengths and weaknesses. The main strengths of statistical (regression-based) models are their simplicity and ease of use. Their highly simplified, correlative representation of ecological responses requires minimal parameterization (calibration) and few driving variables, thereby enabling rapid assessments with a minimal amount of resources. However, this simplicity is also their main weakness. Statistical models generally do not provide an unambiguous means for linking effects to specific stressors – for example, is a decline in a wildlife population due to a chemical or to habitat change? Statistical models also cannot make scientifically defensible predictions about responses for which there are no historical precedents, e.g., novel future combinations of physical, chemical and biological conditions that are outside the range of data for which a model was developed. Questions like these are best addressed with process-based models, i.e., models that explicitly represent key ecological processes and the interactions among them. By capturing important process-level interactions, properly constrained process-based models can isolate the effects of specific stressors and extrapolate those effects for novel combinations of interacting stressors. This predictive and explanatory power comes at the cost of difficulties in developing the scientific understanding to accurately model the relevant processes, and in assembling the detailed data needed to apply these models. The choice of statistical or process-based model will be determined by available resources, time and objectives. However, given their complementary strengths, strong consideration should be given to using both types of models in tandem. For example, statistical models can be used as screening tools to identify organisms or ecosystems at greatest risk, thereby providing a triage assessment for focusing more detailed process-based modeling studies.

2) Broad applicability. The most useful models are those that are broadly applicable to a wide variety of ecosystems (agricultural systems, grasslands, forests, etc.) and regions (arid to humid). Although convenience is one advantage, the primary importance of broadly applicable models is that they establish a consistent framework for analyzing and comparing stressor effects. The internal consistency provided by a single "generalized" model helps ensure that regional differences in predicted ecological responses (e.g., changes in water quality) are due to physical or biological variables, not to differences in the processes and parameters represented in a variety of models.

3) Scalability. The means by which models extrapolate fine-scale ecological knowledge to coarser scales is an important consideration when risks must be predicted across large temporal and spatial scales – e.g., days to centuries, headwater catchments to great river basins. Although many ecological models are designed for this purpose, the underlying statistical and mathematical techniques differ greatly among models and are the subject intense research and debate (Rastetter et al. 2003; Kratz et al. 2003). Thus, the selection of well-validated scaling tools is central to the success of large-scale assessments (see *(4)*, below).

4) Scientific defensibility (model validation). Any model used to inform policy decisions must be scientifically defensible with respect to theory and application. Many aspects of model performance can be validated directly through comparison to experimental and environmental data for which the model was not parameterized. Unfortunately, direct validation of long-term model predictions is not possible – except for the unrealistic option of waiting the requisite time. Nonetheless, a number of well-established procedures exist for testing long-term model predictions, e.g., by establishing their consistency across a wide range of environmental and developmental (successional) gradients (Rastetter 1995). Although the peer-reviewed, scientific literature is the best guide for assessing a model's validity, it should be recognized that reviewers and journals differ greatly with respect to the criteria and emphasis placed on validation. For example, models may deservedly be published for their theoretical contribution to the field, with verification (or rejection) to come much later.

5) User friendliness and availability. A model's user friendliness is a final but very important consideration. No matter how accurate, broadly applicable, scalable or well-validated, models will find limited use in agency assessments if they are not accessible to client office personnel. User friendliness encompasses many things: pre-specification of parameters and state variables; automated handling of model input and output files; ease of building and applying simulation scenarios; and visualization tools for interpreting model output. In short, modeling tools need to come with a user-friendly "dashboard" so that clients can primarily concern themselves with building "what if" scenarios and simulating the consequences. Because a goal is to have broadly applicable tools that are available to the other groups, we will emphasize tools that are open sources and downloadable.

7. Decision Support Components

WESP will focus initially on two primary decision support components: 1) the decision support platform itself, and 2) representations of the identified ecosystem services of interest: *Biological*

Greenhouse Gas Regulation, Water Quality and Quantity Regulation, Wildlife Populations and Habitat, Fish Populations and Habitat, and Air Quality Regulation, in the form of appropriate models capturing key drivers, stressors, and processes. These are described in more detail below.

Decision Support Platform

Background:

Multiagent models such as *Envision* have emerged recently as a useful paradigm for representing human behaviors and decision-making (Parker et al. 2003, Janssen and Jager 2000, Ostrom 1998) within the context of analyzing biophysically complex interactions (Beisner et al. 2003, Holling 2001, Jager et al. 2000, Levin 1998, O'Neill et al. 1986). Multiagent modeling is a broad endeavor, relevant to many fields and disciplines with interest in modeling the behavior of autonomous, adaptive agents (actors). We choose *Envision* for this study because it provides a unique capability to explicit represent policy alternatives, is spatially explicit, allows integration of multiple submodels, allows rich representation of both individual actor and institutional interaction and behaviors, and can model uncertainty in scenario outcomes via Monte-Carlo simulation. *Envision* allows a rich description of human behaviors related to land management decision-making through the three-way interactions of *agents*, who have decision making authority over parcels of land, the *landscape* which is changed as these decisions are made, and the *policies* that guide and constrain decisions (**Figure 6**). In *Envision*, agents are entities that make decisions about the management of particular portions of the landscape for which they have management authority, based on balancing a set of objectives reflecting their particular values, mandates, and the policy sets in force on the parcels they manage. These values are correlated with demographic characteristics and, in part, guide the process agents use to select policies to implement. Policies consistent with agents' values are more likely to be selected. Policies in *Envision* capture rules, regulations, and incentives and other strategies promulgated

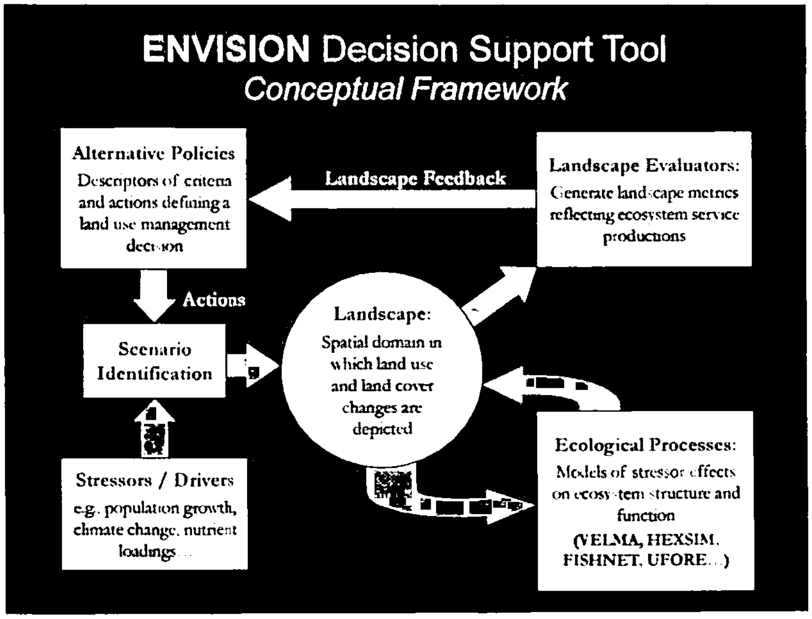


Figure 6. Envision Representational Framework

by public agencies in response to demands for ecological and social goods, as well as considerations used by private landowners/land managers to make land use decisions. They contain information about site attributes defining the spatial domain of application of the policy, whether the policy is mandatory or voluntary, goals the policy is intended to accomplish, and the duration for which the policy, once applied, will be active at a particular site. *Envision* represents a landscape as a set of polygon-based geographic information system (GIS) maps and associated information containing spatially explicit depictions of landscape attributes and patterns. As agents assess alternative land management options, they weigh the relative utility of potentially relevant policies to determine what policies they will select and apply at any point in time/space, if any. Once applied, a policy outcome is triggered, modifying site attributes, resulting in landscape change. Policies may also be constrained to operating only with selected agent classes (e.g., homeowners, owners near federal lands, owners with scenic views etc.).

The key elements in *Envision* are a landscape representation, actors, policies, landscape evaluators and autonomous landscape processes and feedbacks. *Envision* uses a "pluggable" architecture that allows conformant models of landscape productions and autonomous landscape change processes to be included in its simulations and provide information that can be fed back into actor policy selection and decision-making. These models can span ecological, economic or socio-cultural dimensions. Autonomous landscape change models are used to model processes that are not a result of human decision-making, but rather are independent of that decision-making. Characterizing emergent scarcity or fire risk to valued landscape productions is an important aspect of *Envision* that is one factor that may influence actor decision-making. *Envision* allows user definition of which productions are considered valuable in a given study area. From previous work in Oregon's Willamette Valley (Hulse et al. 2002, Bolte et al. 2007), we have developed a variety of conformant models spanning economic, social and ecological dimensions. The research proposed here will add new evaluative models to examine habitat production, fire risk, and economic production related to biofuels, resource extraction, land development and carbon in fire-prone landscapes.

Approach:

Envision currently contains many of the desired attributes of the WESP decision platform. Additional modifications will be implemented as needed to support the project. Primary emphasis will be on the development of relevant "plug-in" models of ecosystem services, described more fully below. Additional analysis capabilities for bundled ecosystem service assessments will be developed specifically for the WESP project and incorporated into *Envision*. An example of a depiction of a bundled output is given in **Figure 7**. Scenarios reflecting management alternatives will be developed in consultation with our clients/stakeholders, through a process to be developed in the first year of WESP.

Expected Outcomes:

- 2011. Prototype decision support platform developed, incorporating basic datasets and initial representations of multiple ecosystem services, for the Willamette basin, with primary focus on greenhouse gas regulation strategies and scenarios. The goal is to test/demonstrate the utility of the *Envision* framework for integrated ecosystem service assessments.

- 2012. Incorporation of additional ecosystem service models into the decision framework; models: The goal will be to demonstrate decision support capabilities for assessing the effects of agricultural, riparian and forest management practices on tradeoffs among multiple forest ecosystem services, including regulation of food/fiber production, water quality and quantity, carbon sequestration, greenhouse gases, and reactive nitrogen.

- 2013. Incorporation of the full set of initial ecosystem service models into the WESP decision framework, with application at two scales – a fifth-field watershed and the entire WRB; development and implementation of a full set of scenarios reflecting management alternatives for ecosystem service provision relevant to identified clients/stakeholders; assessment of results and approach.

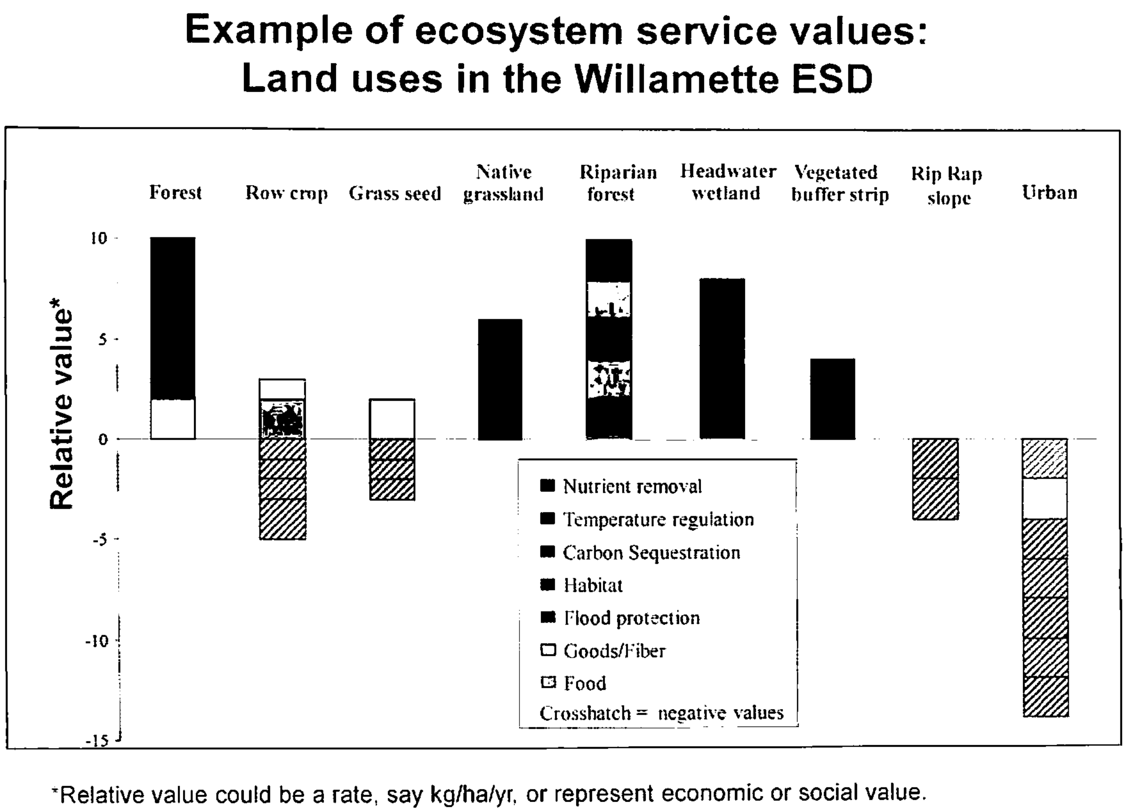


Figure 7. Graphic Depiction of the tradeoffs and bundling of ecosystem services within land use categories.

Water Quality/Water Quantity Modeling

Background:

The EPA Western Ecology Division (EPA-WED) has collaborated with the Georgia Institute of Technology to develop an ecohydrologic modeling framework to meet these emerging risk assessment objectives more closely than other currently available models. This framework links a suite of process-based models to address the effects of changes in climate. land use and other interacting stressors on multiple ecosystem services: production of food and fiber, carbon sequestration, regulation of water quality and quantity, reduction of greenhouse gases, and regulation of sources and sinks of reactive nitrogen within watersheds. The central model in this framework is VELMA (Visualizing Ecosystems for Land Management Assessments), a spatially-distributed ecohydrologic model that links a land surface hydrologic model (GTHM, the Georgia Tech Hydrologic Model) with a terrestrial biogeochemistry model (PSM, the Plant Soil Model) (Stieglitz et al. 2006a, 2006b, Abdelnour et al. 2006, Cheng et al. 2006, Pan et al. 2008). The coupled models provide an approach for simulating the integrated responses of vegetation, soil, and water resources to interacting stressors (**Figure 8**). VELMA is applicable to a variety of ecosystems (forest, grassland, agricultural, tundra, etc.) and spatial scales (hillslopes, catchments, basins), and is well-suited to predicting changes in carbon sequestration in plants and soils, pollution of surface waters, and the severity of floods and droughts affecting regional water supplies – all vital ecosystem services that pose major policy and regulatory issues for EPA and other federal and state agencies.

VELMA differs from other available ecohydrology models in its simplicity and theoretical foundation. For the hydrologic component, GTHM is typically applied using 30 x 30-meter landscape units, although user-defined units of any size and shape are possible (m^2 to km^2). GTHM requires calibration of just three parameters to simulate evapotranspiration, infiltration, and surface and subsurface runoff. In contrast, HSPF, the primary hydrologic model in EPA's BASINS water quality assessment framework, requires calibration of dozens of parameters. For the biogeochemical component, PSM is based on just four differential equations to simulate daily changes in total plant and soil C and N stocks, and dissolved carbon and nitrogen (DIN, DON, DOC).

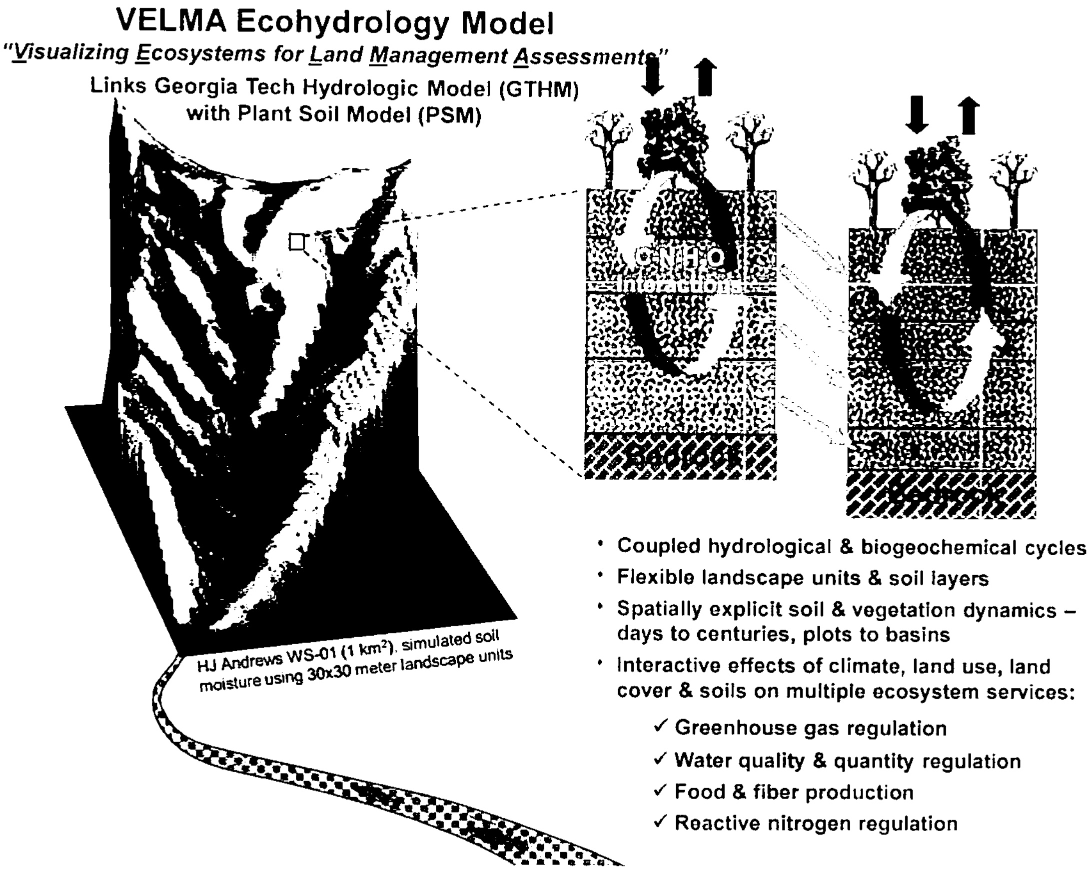


Figure 8. Conceptual diagram of the VELMA ecohydrology model.

This simplicity increases the speed and scale of VELMA applications, while still capturing salient hydrological and biogeochemical responses for a variety of ecosystems. For example, recent work has been aimed at validation tests of VELMA for several Long Term Ecological Research (LTER) sites: temperate coniferous forests at the HJ Andrews LTER in Oregon's Willamette River Basin: tallgrass prairie at the Konza Prairie LTER in the Flint Hills of Kansas: and temperate deciduous forests at the Hubbard Brook LTER in New Hampshire. This work has established the broad applicability of VELMA across major biomes, while providing a foundation for EPA's regional-scale projects in the Willamette River Basin (WRB) and Flint Hills rangelands. Comparison of simulated and observed data demonstrates good agreement for the effects of climate and land use on key ecosystem processes that regulate ecosystem services. Models tests thus far have focused on the effects of climate and land use (e.g., harvest, fire and grazing) on stream discharge and chemistry, ecosystem carbon and nitrogen dynamics, vegetation productivity, and accumulation of fuel loads.

Approach:

For WESP, we will link VELMA with the *Envision* decision support system to provide EPA clients and other stakeholders with a user-friendly interface for exploring the consequences of alternative land use and climate scenarios on ecosystem service tradeoffs in the WRB. Our objective is to integrate *Envision's* decision support capabilities (user-defined stressor scenarios, decision rules, evaluation indices, landscape visualization, etc.) with VELMA's capabilities for assessing how alternative decisions simultaneously affect multiple services (e.g., **Figure 9**). Outputs will be model-generated maps of predicted changes and tradeoffs among ecosystem services, both in biophysical and economic terms. Target ecosystem services will include: regulation of water quality and quantity, carbon sequestration, production of food and fiber, reduction of greenhouse gases (CO_2, N_2O, NO_x), and regulation of sources and sinks of reactive nitrogen (Nr) within watersheds. Our main goal is to provide a flexible framework for integrated assessments that identify policy and management strategies for entire ecosystems and the bundled services they provide, rather than piecemeal assessments of individual services.

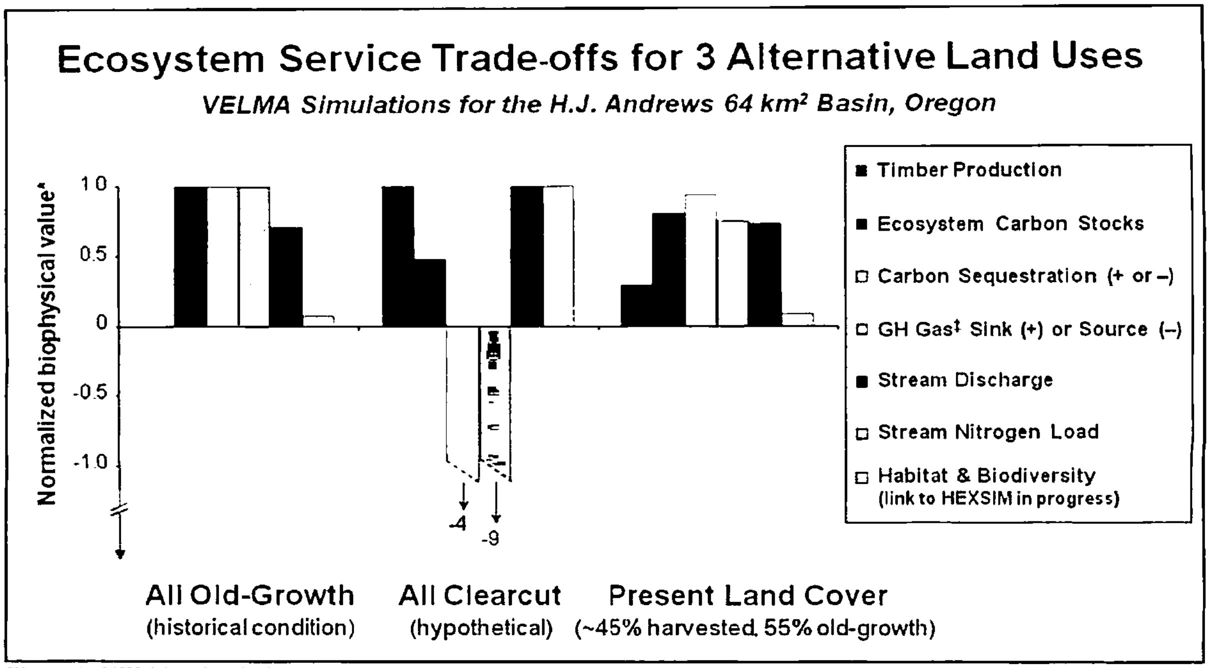


Figure 9. VELMA simulations demonstrating ecosystem service tradeoffs for alternative land uses in a forested landscape in the WRB's Cascade Range.

As a proof-of-concept test for developing the linkage between VELMA and *Envision*, we will begin with two sub-basin applications for the WRB. The first application will be for the existing "*Envision* Andrews" project, a 2,000 km^2 area of federal, state and private forest lands in the western Cascade Range that includes the HJ Andrews LTER site. The second application will be for the Calapooia watershed, a 1,000 km^2 landscape characterized by headwater forests and lowland agricultural lands. Because these two test areas encompass much of the variability in land use, land cover, topography, soil and climate found in the WRB, they provide an excellent test bed for developing the model linkages, scenarios and valuation metrics needed for basin-scale applications. The west Cascades and Calapooia applications will be conducted during 2010-2012, with the basin-scale application of *Envision* to be completed by 2013.

Additional improvements to VELMA will be made during 2010 – 2012 to facilitate the WRB applications. The most important improvement will be to develop hardware and software solutions for increasing the speed and scale of VELMA applications. Although the model has been successfully implemented for 5th order watersheds (e.g., the 64 km^2 H.J. Andrews watershed), we are considering a number of strategies for applying VELMA at much larger spatial scales, such as the WRB. An additional set of improvements will involve coupling VELMA with several existing models to better assess the effects of changes in land use and climate. For example, we plan to use VELMA in combination with a topographically responsive climate simulator (Daly et al. 2007), a snowpack simulator (e.g., Stieglitz 1994), a soil temperature simulator (Stieglitz et al. 2001), and a stream network model (Liu and Weller 2007). These improvements will also facilitate the planned linkage VELMA and HexSim (Schumaker et al. 2004), an individual-based wildlife population model adaptable to simulating a variety of terrestrial and aquatic species (birds, mammals, fish, etc.) – see "Wildlife Populations and Habitat," below.

To address water quality/quantity issues not presently addressed by VELMA, we will also investigate collaborative opportunities with investigators who are applying other hydrologic models. For example, the CE-QUAL-W2 TMDL model (Annear et al. 2004) is an integrated stream temperature model developed specifically for the WRB to examine alternative temperature management strategies and their tradeoffs. The model consists of a series of systems dynamics models that include the effects of outflows from multiple reservoirs, permitted industrial and municipal discharges, land-use types, and irrigation practices. Investigators with the Sandia National Laboratory, Willamette Partnership, U.S. Army Corps of Engineers and others are developing the model to inform policy decisions in the basin, specifically in the context of developing temperature trading markets.

Expected Outcomes:

- 2011. Application of VELMA coupled with *Envision* for the 2,000 km^2 "*Envision* Andrews" forested landscape in the WRB's Cascade Range. This will be an initial proof-of-concept demonstration of the coupled ecohydrology/decision support framework for assessing the effects of alternative forest management on tradeoffs among multiple forest ecosystem services, including regulation of water quality and quantity, timber production, carbon sequestration, greenhouse gases, and reactive nitrogen.

- 2012. Application of VELMA coupled with *Envision* for the 1,000 km^2 Calapooia watershed, a mixed agricultural and forest landscape in the WRB. The goal will be to demonstrate decision support capabilities of the coupled framework for assessing the effects of agricultural, riparian and forest management practices on tradeoffs among multiple agricultural and forest ecosystem services, including regulation of food/fiber production, water quality and quantity, carbon sequestration, greenhouse gases, and reactive nitrogen.

- 2013. Application of VELMA coupled with *Envision* for the entire 30,000 km^2 WRB, including agricultural, forest and riparian land uses, demonstrating basin-scale dynamic decision support capabilities for assessing and valuating tradeoffs among multiple ecosystem services in response to alternative policy, management and climate scenarios. This application will incorporate several improvements to VELMA, including (1) development of hardware/software solutions for increasing the speed and scale of model applications for large landscapes/basins; (2) incorporation of spatially-explicit climate and snowpack simulators, and a stream network model; and (3) coupling with the HexSim wildlife population model for assessing the effects of changes in habitat and climate on terrestrial and aquatic species.

Greenhouse Gas Regulation and Carbon Modeling

Background:

The Millenium Ecosystem Assessment (2005) defines regulating services as the benefits obtained from the regulation of ecosystem processes. Ecosystems help regulate climate by controlling the fluxes of greenhouse gases that cause radiative warming of the atmosphere. In particular, ecosystems have significant fluxes of CO_2 from a number of processes including CO_2 fixation in photosynthesis and CO_2 release in respiration and decomposition. These processes are influenced by a variety of biotic and abiotic factors including temperature, moisture, disturbance, mortality, etc. The balance of photosynthesis versus respiration often results in "net ecosystem production" where there is net sequestration of CO_2 in biomass and soil C pools, thus reducing the rate of atmospheric CO_2 buildup, although the reverse can also be true under conditions of natural or anthropogenic disturbance. Thus, it is important to estimate the magnitude and spatial distribution of greenhouse gas fluxes in WRB ecosystems in order to assess this ecosystem service and how it is affected by different stressor scenarios.

Approach:

Changes in biomass and soil C pools will be used as indicator variables for ecosystem regulation of CO_2 and other C-based greenhouse gases such as methane (CH_4). Several different modeling approaches will be used to assess the current condition of C pools in the WRB and how they would change under alternative scenarios of land use/land cover and climate change in the future. These models vary in complexity from models based on single-endpoint look-up tables to complex multiple-endpoint process models.

Biomass C density model

To assess biomass C pools under each of the 1990-2050 scenarios devised in the Willamette Alternative Futures Project (Hulse et al. 2002; Baker et al. 2004). Phillips et al. (2010) conducted an extensive literature and database search for data on biomass C density (C per unit area) for different land cover classes in this region. The 65 land cover classes used by the Willamette Alternative Futures project provided too fine a classification, so those were aggregated into 23 cover classes for assigning biomass C densities; separate age classes for conifer forests were retained due to their extreme importance in understanding PNW forest dynamics and C cycling. Only data on aboveground biomass C densities were consistently found for all land cover classes; belowground data or root:shoot ratios were found for some, but not all classes. Therefore the analyses were restricted to aboveground biomass only. For each scenario and decade, the total area in a land cover class was multiplied by the aboveground biomass C density for that class to determine its aboveground biomass C pool. These were then summed over all cover classes to determine the basin-wide total aboveground biomass C pool.

This procedure utilized the existing future land use/land cover maps constructed for the Willamette Alternative Futures Project reflecting Plan Trend, Development, and Conservation scenarios for development through 2050. For WESP, *Envision* will be used to produce new spatially explicit land use/land cover scenarios consistent with other specified policies (for C offset forestry, for example) for selected sub-basin areas and across the entire WRB. This simple biomass C density model will be linked with *Envision* to assess biomass C pools under the alternative scenarios, reflecting differences in ecosystem GHG regulation.

InVEST C model

In a similar fashion, Nelson et al. (2009) used the C model in the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) spatial modeling tool to assess C pools under the 1990-2050 Willamette Alternative Futures scenarios. This model includes biomass (aboveground and belowground), soil, and harvested wood products pools, but does not include C storage in grass or herbaceous vegetation since it was considered insignificant compared to forests. In this model, biomass and soil C densities are assigned by look-up tables based on literature and data bases, but modified to account for time since transitioning to that cover type; see Nelson et al. (2009) and its appendices for further details. As with the biomass C density model described above, additional analyses for WESP can be done with the InVEST C model by linking it to *Envision*, which can produce new spatially explicit land use/land cover scenarios for specified policies.

STANDCARB model

The STANDCARB model (Harmon and Domingo, 2000) models dynamics of carbon allocation in forest stands. STANDCARB is used in this case to determine long term outcomes from various forestry management regimes and practices. It represents multiple carbon pools, sources and sinks, and is well adapted to conducting assessment of alternative carbon management strategies in forested landscapes over time scale relevant to WESP alternative futures.

VELMA

As described above in the Water Quality/Water Quantity Modeling section, the VELMA ecohydrology/terrestrial biogeochemistry model will also be linked to *Envision* and used in a series of simulations for the H.J. Andrews area, the Calapooia watershed, and the entire WRB. The outputs of these simulations will include estimates of C flux rates and C pool sizes for vegetation and soils, as well as the water quality and water quantity outputs discussed above.

Expected Outcomes:

- 2011. Application of *Envision* coupled with several C models (including VELMA) for the 2,000 km^2 "*Envision* Andrews" forested landscape in the western Cascade Range within the

WRB. This will be an initial proof-of-concept demonstration of the coupled ecohydrology/decision support framework for assessing the effects of alternative forest management on tradeoffs among multiple forest ecosystem services, including regulation of water quality and quantity. timber production, carbon sequestration. greenhouse gases. and reactive nitrogen.

- 2012. Application of *Envision* coupled with several C models (including VELMA) for the 1,000 km^2 Calapooia watershed, a mixed agricultural and forest landscape in the WRB. The goal will be to demonstrate decision support capabilities of the coupled framework for assessing the effects of agricultural. riparian and forest management practices on tradeoffs among multiple forest ecosystem services, including regulation of food/fiber production, water quality and quantity, carbon sequestration. greenhouse gases, and reactive nitrogen.

- 2013. Application of *Envision* coupled with several C models (including VELMA) for the entire 30,000 km^2 WRB, including agricultural, forest and riparian land uses, demonstrating basin-scale dynamic decision support capabilities for assessing and valuating tradeoffs among multiple ecosystem services in response to alternative policy, management and climate scenarios. This application will incorporate several improvements to VELMA, including (1) development of hardware/software solutions for increasing the speed and scale of model applications for large landscapes/basins; (2) incorporation of spatially-explicit climate and snowpack simulators. and a stream network model: and (3) coupling with the HexSim wildlife population model for assessing the effects of changes in habitat and climate on terrestrial and aquatic species.

Air Quality Regulation

Background:

Ecosystem processes affect air quality through absorption (but also emission) of air pollutants or through other indirect effects on their concentrations. The benefits that humans derive as a result encompass the ecosystem services referred to as "air quality regulation" (Millenium Ecosystem Assessment 2005). Of particular interest to EPA are "criteria air pollutants" recognized by the Clean Air Act (ozone. particulate matter. sulfur dioxide, nitrogen dioxide. carbon monoxide, and lead). EPA has a need to understand the ways in which ecosystems help regulate air quality. how this regulation varies with environmental stressors and policy drivers. and the economic value of these services.

Approach:

Several existing models assess the absorption of EPA criteria air pollutants (CO. NO_2, O_3. SO_2. PM) by trees and economic valuations of the human health and environmental benefits of these reductions. One of these models, i-Tree Eco (formerly UFORE; Nowak and Crane 2000), will be used to assess air pollutant removal (and its economic value) by trees in one or more urban areas within the Willamette River Basin, based on individual tree data from inventories and/or random plot samples. A second model, i-Tree Vue. which is in a beta test version, will be used to assess air pollutant removals and their economic value basin-wide based on synoptic National Land Cover Dataset (NLCD) land cover data for the WRB.

Expected Outcomes:

2010. Application of i-Tree Eco to assess the removal of air pollutants by trees within the Corvallis Urban Growth Boundary. and economic valuation of these benefits.

2011. Application of i-Tree Vue to assess the removal of air pollutants by trees throughout the WRB, and economic valuation of these benefits.

2012. Application of i-Tree to assess changes in air pollutant removals due to changes in forest cover and structure under several alternative future scenarios (e.g., climate change, forest management for C offsets).

Wildlife Populations and Habitat

Background

The complications introduced by multiple interacting stressors are central to the research proposed here because our intent is to forecast wildlife population dynamics in realistic, and thus complex settings. This study's over-arching research question can be stated as: How do we develop a rapid yet useful methodology for predicting wildlife population responses to anticipated future disturbance in realistic landscapes? The specific focus will be on a subset of the birds and mammals found within Oregon's Willamette River Basin. Landscape change will be simulated by software developed at Oregon State University. This application (*Envision*) provides an infrastructure within which response models can be added; and this research effort will culminate in the generation of one such model. To be useful, our wildlife "plug-in" must be responsive to a range of landscape changes while also being quick to compute. This presents a substantial research challenge as population biologists and modelers have had little success developing simple yet realistic models for even a single wildlife population. This project will endeavor to develop such models for a suite of species, all inhabiting a large and extremely complex landscape.

Wildlife populations often face multiple threats. Habitat loss and fragmentation, pesticides. exotic species, pollution, over-exploitation. and disease all have major impacts on population viability. Habitat loss. the most pervasive threat. impacts over 80% of the at-risk species in the United States (Wilcove et al. 1998). Most habitat loss is the direct result of agriculture, construction, or resource extraction that dramatically alters a landscape. The habitat that remains is often fragmented or impacted by other human activities. Exotic or introduced species are the second most common threat. affecting 49% of the at-risk species in the United States (Wilcove et al. 1998, Wilcove and Master 2005). In the last twenty years, a new, far reaching threat has been identified. Average global temperatures are expected to rise between 1.4 and 5.8 °C in the coming century (Houghton et al. 2001). Changes in the Earth's climate have already led to shifts in species distributions (Parmesan et al. 1999, Thomas and Lennon 1999) and changes in phenology (Beebee 1995, Crick and Sparks 1999). Furthermore, climate change has been clearly implicated in species extinctions (Pounds et al. 1999).

When a species faces multiple threats, the threats can interact in several different ways. Some threats are likely to act additively, some synergistically, and in some cases the effects of one intense threat may make the others relatively unimportant. Some of the better documented interactions involve synergistic effects in which together two or more human activities produce a greater impact than a purely additive combination of their individual effects would suggest. For example, road building and construction, which tend to impact at-risk species by altering and destroying habitat, may interact with other stressors. These activities can increase exotic species populations by providing access routes and reducing competition from native organisms (Parendes and Jones 2000, Gelbard and Belnap 2003). As a second example, exotic species may act to further alter natural disturbance regimes, thus compounding the effects of human activities such as fire suppression and grazing (Mack and D'Antonio 1998).

Approach

This project will not have the time or resources necessary to gather new data or develop substantially new models. Instead, we will work with data sets developed as part of the Willamette Alternative Futures project (Schumaker et. al 2004) and also data developed by collaborators at the US Forest Service and the University of Washington. The wildlife model we will use for this work is HexSim, which is under development at the US EPA. HexSim will be parameterized with the available wildlife data and used to construct simple "proxy models" that are species-specific but incorporate sufficient realism without sacrificing efficiency.

In the context of this work, the challenges presented by ecosystem services are the needs for accuracy, extensibility, and computational efficiency. The wildlife models used must produce plausible outcomes that can be independently evaluated by biologists and managers. But these models must be used to make large numbers of assessments within any given *Envision* simulation, and thus they must be fast to compute. Accuracy and efficiency are hard to build into a single model -- more attention to one property typically means less focus on the other. Extensibility means the wildlife models might be adapted for additional species, landscapes, or disturbance regimes. Extensibility increases the likelihood that the research will ultimately benefit stakeholders and decision makers, as these individuals' needs are always changing.

Our use of HexSim will make it possible to balance accuracy, extensibility, and efficiency. HexSim is a spatially-explicit, individual-based computer model designed for simulating terrestrial wildlife population dynamics and interactions. HexSim is very general, with landscapes, life histories, disturbance regimes, and most other details being supplied by the user at run-time. HexSim includes a sophisticated graphical user interface (GUI). The model uses spatial data to capture landscape structure, habitat quality, stressor distribution, and other types of information. HexSim can work with real or fabricated landscapes. HexSim's design makes it ideal for exploring the cumulative impacts of multiple interacting stressors.

HexSim simulations are built around a user-defined life cycle. This life cycle is the principal mechanism driving all other model processing and data needs. Users develop the life cycle when initially setting up a simulation. The life cycle consists of a sequence of life-history events that the user selects from a palate. The event palette includes survival, reproduction, movement, resource acquisition, species interactions, and many other actions. Through the creative use of events, the user can impose yearly, seasonal, daily, or other time cycles on the simulated population. Each event can work with all, or just a segment of a population, and events can be linked to static or dynamic spatial data layers. Each life-cycle event has its own data requirements.

HexSim populations must be assigned traits. Traits are population-specific, but are implemented at the level of the individual. Traits can change probabilistically or based on an individuals surroundings and experience. Traits can also be genetic and thus heritable. What makes HexSim's traits particularly valuable is that users can set them up any way they see fit, and the traits can then be used to control most life cycle events. Traits influence population dynamics because events can be stratified by trait combinations. For example, a fledgling age class could be captured as a trait category, and a movement event might act only on individuals with this trait value. Or a survival event might assign mortalities based on the values of a trait that reflects resource acquisition. In addition, one trait's values can also be influenced by multiple other traits, which makes it possible to set up stressor interactions and complex feedback loops. Traits can also be used to capture interactions such as parasitism, competition, mutualism, breeding, and so on.

HexSim simulations can be as simple or detailed as data and research needs dictate. And HexSim can be used with a wide array of terrestrial wildlife species, landscapes, and disturbance regimes. However, HexSim is not quick or compact enough to meet the criteria for an *Envision* plug-in. The development of a plug-in for *Envision* will be accomplished by using HexSim to design population projection matrix analogs to its detailed simulations.

The realism that HexSim simulations can capture often translates into highly variable results. Simulation outputs such as population size can vary greatly in time and across replicates. Many replicate simulations, each of long duration, are often needed to estimate mean population growth rates with any reliability. When landscape change is subtle, this variability can easily mask the signal reflecting any changes in population viability. But these changes are exactly what a model like *Envision* needs to supply its feedback-based evaluation algorithms.

HexSim has the ability to generate a report that uses simulation data to construct a population projection matrix. The matrix dimension is equal to the number of trait combinations built into the HexSim simulation. The projection matrix report groups every transition between trait categories, including reproduction and mortality, and assembles a single projection matrix. This projection matrix can be used to compute the steady-state population growth rate (λ), which provides a straightforward assessment of population viability.

The projection matrices described above do not capture landscape change explicitly. But doing so will be necessary for this work. This will be achieved through a two-step process. In step one, HexSim scenarios will be developed for multiple wildlife species that include traits which capture landscape structure and resource acquisition. These scenarios will be run with multiple different landscape maps and used to develop a diverse collection of projection matrices. In step two, we will compute pattern metrics for each of the landscapes and then identify functions that relate the data in a given matrix cell to the pattern metrics derived from the landscape used to generate the matrix. The result will be a matrix of functions, where each function depends on measures of landscape structure. There will be a single matrix per wildlife population. These matrices will be added to the *Envision* software, along with whatever tools are required for *Envision* to compute the requisite pattern metrics.

Even with the variable terms included, the projection matrix proxy models should be extremely fast to compute. In addition, because HexSim is being used to develop the initial matrix models, the target wildlife populations can be described in as little or as much detail as we choose. Our approach will be to start with the data for some or all of the wildlife species examined in the Willamette Alternative Futures project (Schumaker et. al. 2004). but then to add realism as the study progresses. The wildlife populations examined in the Willamette Alternative Futures study included black-capped chickadee, blue grouse, bobcat, Cooper's hawk, coyote, Douglas squirrel, gray jay, great horned owl, marsh wren, mourning dove, northern goshawk, northern spotted owl, pileated woodpecker, raccoon, red fox, red-tailed hawk, and western meadowlark.

Expected Outcomes

The principal goal of this work will be the generation of proxy models that serve as plug-ins for *Envision*. There will be one such model developed for each wildlife species examined. The wildlife species studies will represent a subset of those included in the Willamette Alternative Futures project, plus any for which scenarios are developed by our cooperators.

The secondary goal of this work will be manuscripts that describe the process and benefits of the HexSim projection matrix summaries. There is a potential for this work to add substantially to the disciplines of landscape ecology and conservation biology, in both theoretical and applied arenas.

Timeline

2010: Initial scenario and matrix model development work. Initial linkages to *Envision*.

2011: Development of a full suite of wildlife scenarios. Improve *Envision* linkages.

2012: Development of a full suite of projection matrices.

2013: Add model realism. Improve proxy models.

Fish Populations and Habitat

Background

A number of computer models have been developed that simulate the movement and breeding of individual organisms on a landscape over lengths of time sufficient to measure persistence. Some models have been generalized to study any species that has appropriate behavioral dynamics. For example, the HexSim model described above simulates complex individual organism behavior in a spatially varying and temporally dynamic environment.

Few comparable efforts have been made to look at the dynamics of fish species assemblages and diversity. Although a number of research models have been published, this work usually has been a one-time effort, rather than a generalizable approach. Furthermore, few if any organismal models, including spatial demographic models, have been implemented in the setting of a directed acyclic network to simulate population processes in river systems.

Approach

The research proposed here will apply an age/stage structured population model for one or more fish species in the parts of or the entire Willamette River network. The model will use either yearly or seasonal timesteps and comprise the following processes taking place for each age class for each species in each segment of the network: determining habitat suitability, calculating survival and reproduction, and moving sub-populations to nearby segments. The initial WESP fish model will use a relatively simple implementation of these processes for inclusion as a plug-in to *Envision*, based on a recent model developed by Brenda Rashleigh of ORD/NERL/ERD in Athens, GA.

The purpose of the Rashleigh model is "for projecting changes in stream fish assemblages, and the ecosystem services they provide, in response to multiple stressors across stream networks within watersheds. The model has a yearly timestep and consists of three parts: habitat suitability, population dynamics, and species movement. We use a multiple regression habitat suitability approach to represent the effects of multiple stressors on populations. Multiple regression can represent multiple stressors, as well as their covariance. Species dynamics are represented by an age/stage structured population matrix model for survival and reproduction. Simple rules are used to represent movements of species in river networks. This model has been applied to a test watershed in the Albemarle-Pamlico watershed, to forecast how species, particularly those that are important service providers, change in abundance over time, and under different scenarios. A long term goal is to link this model with watershed and instream models in an integrated modeling framework, so that multiple ecosystem services may be assessed." (Rashleigh, 2009)

The Rashleigh model is similar to an earlier model developed by Baker and White (2005). This model is also a spatially-explicit, age-structured population model, simulating one or many interacting fish species over multiple years. Time steps can be seasons or years. The spatial unit represented is a stream segment, equivalent to a stream reach. Each segment has one or more habitat attributes. Mature fish can move among segments in the stream network to find suitable areas for spawning. All fish can move among segments to disperse or find areas with better habitat. Fish survival is affected by habitat conditions, intra- and inter-species competition, and predator-prey interactions. Model output is numbers of fish by species and age class in each segment of the stream network at each time step. Results can also be expressed as species richness and fish index of biotic integrity (IBI) (Baker and White, 2005).

A conceptual diagram influencing development of both the Rashleigh and Baker-White models shows a network in the Oregon Coast Range modeled by the Baker-White model with landscape impacts and in-stream habitat influencing the populations of species in an assemblage (**Figure 10**). A second diagram illustrates the population cycle of a sample species as depicted in these models (**Figure 11**).

After the initial implementation of the Rashleigh model during FY2010, a program of enhancements will be undertaken to add some of the features of the Baker and White model such as more sophisticated movement and seasonal time steps with corresponding additions to vital rates and habitat requirements. This work will continue into subsequent fiscal years 2011 and 2012.

For implementation in the Willamette River Basin the initial model will use a coarse representation of the river network (**Figure 12**), a small number of species, and habitat relationships based on an analysis of fish samples in the basin, using techniques applied in previous studies (Rashleigh et al. 2005). The intention is to use an anadromous salmonid as one of the species because of the great importance of these species in the Pacific Northwest. To this end, the river network is augmented with two symbolic segments beyond the mouth of the Willamette to represent the Columbia River from the confluence with the Willamette to its mouth at the ocean, and the ocean itself (**Figure 12**). These two symbolic segments will be populated with length and habitat attributes to simulate conditions that the migrating salmonid species encounters. Other species may include an introduced species, of which there are now many in the basin, and two or three other species representing other functional types of species. Future improvements to this representation will include adding smaller order tributaries, subdividing the initial confluence-to-confluence segmentation by ecoregions, initially, then by geomorphologically significant features, and inserting the dams that strongly affect fish passage on many tributaries.

The fish model will be fully coupled in the *Envision* framework and interact dynamically with other models, particularly the water quantity and quality models, supplying data for in-stream habitat. By integrating the fish modeling in *Envision*, this modeling will also be reporting results for display and analysis by *Envision's* decision support tools.

In addition to the basin-wide modeling there will be an additional modeling component that will be conducted in collaboration with the Non-navigable Streams and Wetlands Project of the Water Quality MYP. This activity will model the Calapooia River tributary of the Willamette River and specifically focus on the effects of small streams on fish assemblage properties.

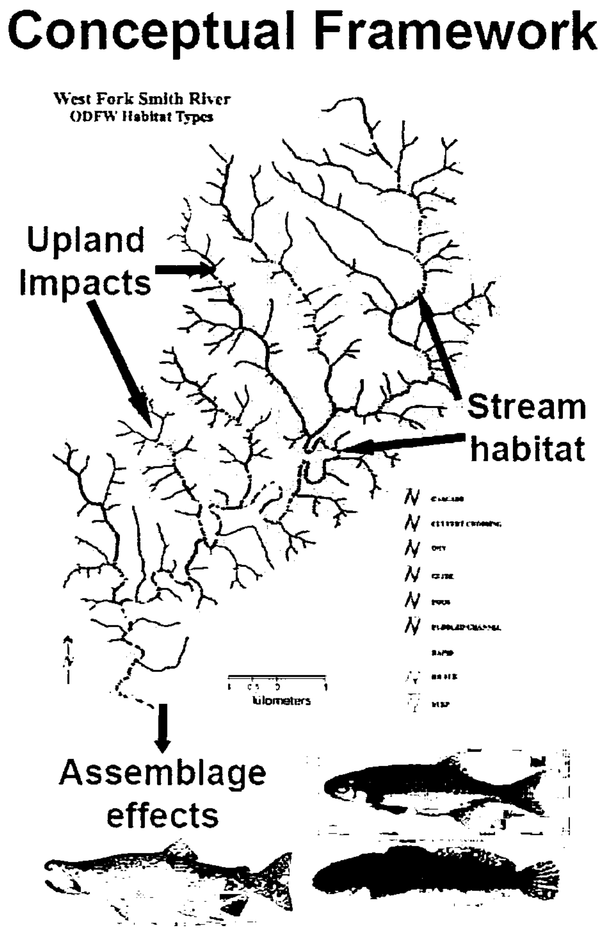


Figure 10. Conceptual diagram of watershed and in-stream habitat effect on fish

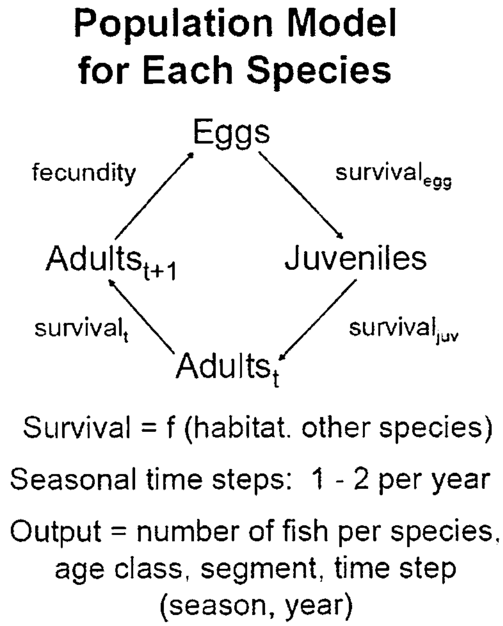


Figure 11. Conceptual diagram of population cycles for fish species

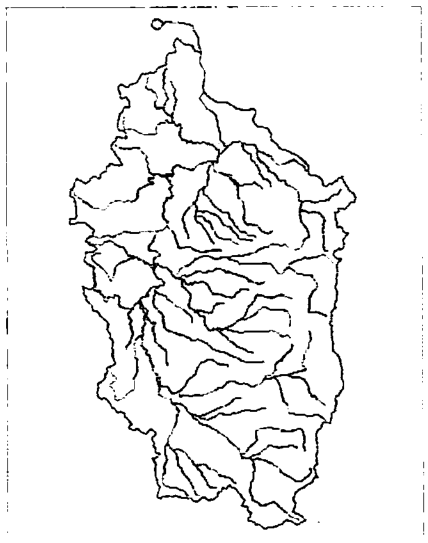


Figure 12. The Willamette River network including only major tributaries, plus symbolic segments representing the Columbia River (curved linear segment exiting the Willamette basin at the top) and the ocean (almost circular segment at the end of the Columbia segment).

Expected outcomes

2010: An initial plug-in for *Envision* based on the Rashleigh model for the coarse scale Willamette network using four to five species including one salmonid, one introduced species, and two to three others.

2011-2012: Improvements to the initial model for seasonal time steps, improved detail for the Willamette network, more species, and better data and models for the processes of habitat selection, interspecies interactions, and fish movement.

Additional Ecosystem Service Assessments

There are a large number of ecosystem services potentially relevant to WESP; examples are provided in Appendix 2. We recognize that as the project unfolds, additional ecosystem service representations may be needed, e.g. pesticide/integrated pest management with impacts of pollinators, habitat, and water quality. Further, linkages with related EPA efforts will be pursued where possible: examples include ongoing floodplain restoration work at Green Island in the Willamette and the Carbon Offset Forestry activities at WED. Our goal with these collaborations is to ensure that data collection, modeling, and outreach activities are well aligned with WESP activities where needed: for example, water quality monitoring studies at Green Island can potentially inform WESP modeling activities related to hyporheic flow, stream temperature, and fish habitat analysis. We will work with Green island researchers to develop synergies between these two projects. Additionally, inclusion of market and non-market evaluations may be useful for some analyses. Our decision platform is readily extendable to incorporate these representations as they become available. We will look for opportunities to extend into these additional areas as resources and expertise becomes available.

Sensitivity and Uncertainty Analyses for the WESP Decision Platform

There is a large literature on sensitivity and uncertainty analysis (see recent textbooks by Cacuci 2003, Cacuci et al. 2005, and Saltelli et al. 2004 for introductions). Within WESP we recognized the need to address uncertainty at two fundamental levels: 1) uncertainty associated with model calibration and validation, and 2) uncertainty associated with aggregate analysis within an alternative futures context. We address model uncertainty first, followed by uncertainty associated with integrated assessments within the DSP.

"Uncertainty analysis is an important component of the overall modeling strategy. For statistical models, uncertainty analysis should be straightforward, as all error terms are usually generated in the model fitting (calibration) process. For mechanistic (process-oriented) models, complete uncertainty analysis is a major challenge. It may be possible to estimate univariate distributions for uncertain parameters, but the error covariance between parameters (which can be quite important in error propagation) is often quite difficult to determine. Further, estimation of error in the model equations is an even greater challenge. Thus, it is important, when presenting the results of an uncertainty analysis, to clearly indicate how the error terms were estimated, and what error terms were not included in the analysis" (Johnston et al. 2008).

"One option to consider for calibration of a process model is to use a technique that yields parameters sets, not individual parameters. Imbedded in these sets is a covariance structure. New methods to consider for parameter estimation include Generalized Likelihood Uncertainty Estimation (GLUE) and Markov Chain Monte Carlo (MCMC) methods" (Johnston et al. 2008).

"Model validation involves comparing predictions and observations for an application of a model on data that were not used in calibration. Given the limited amount of data in many modeling studies, the modeler may be forced to calibrate with one year's data and validate on the data collected in the following year. It is unlikely that two consecutive years will be vastly different, so the validation exercise may not be too meaningful. Ideally, validation should indicate that the model will perform as the actual ecosystem responds when management actions change some of the forcing variables (e.g., nutrient loading) substantially. Unfortunately, having data that allow this degree of validation is likely to be quite rare. Thus an option to consider is to rate the rigor of the validation exercise by how much the calibration data distributions differ from the validation data distributions" (Johnston et al. 2008).

Although predictions of complex models (statistical or process-based) cannot be validated in a strict sense (Rastetter 1995), comparisons against a variety of observations and criteria are essential for characterizing model uncertainty and building confidence in a model. In part, such confidence will be proportional to the range of environmental conditions across which a model accurately portrays responses. Similarly, validation methods that employ multiple criteria for assessing model performance provide the most rigorous means of establishing confidence in a model. For example, Reynolds and Ford (1999) describe a multiple-criteria model assessment methodology for characterizing uncertainty associated with ecological theory, model structure, and assessment (validation) data. We will investigate such methodologies for testing WESP models. The success of this will depend on the availability of high quality data sets for the purposes of model calibration and validation. We anticipate that the research described in Section 3.3 for the four major WRB land use types will provide a data-rich foundation for this effort.

Sensitivity analysis is another aspect that will be developed in the WESP Modeling Strategy. Traditional sensitivity analyses determine the rate of change of model output as a single input is varied by a small amount, while holding the other inputs constant. These rates of change are often converted into relative measures to facilitate comparisons among different inputs. Sensitivity analyses may be used for several purposes, including (a) determining which inputs contribute most to output variability, (b) identifying parameters that are insignificant and may be eliminated from the model. and (c) identifying parameters that require better estimation in order to reduce output uncertainty. McKane et al. (1997) present an example of a sensitivity analysis for a process-based biogeochemistry model that served these purposes.

Uncertainty analysis within the WESP decision platform provides additional challenges, primarily related to the complex interactions of multiple parameters, models, and decision processes that are not based on numerical algorithms. The WESP decision platform integrates qualitative descriptions of decision variables and non-algorithmic decision processes with traditional numerical models. The paradigm for modeling in these synoptic alternative futures assessments is more one of comparative analysis than parameter estimation, i.e., comparing alternative scenarios for their differential outcomes for the suite of services. The first order differences across the suite (with bundling diagrams, for example) are powerful communication results from these kinds of assessments, where the goal is to communicate not a prediction of a specific result, but rather to generate a portfolio of possible outcomes for the alternatives. We contrast the traditional *predict-then-act* paradigm, which pairs models of rational decision making with methods for treating uncertainty derived largely from the sciences and engineering (Raiffa 1968: Lempert et al. 2003), with an *explore-then-test* paradigm which is emerging as a viable approach for more complex, decision-oriented assessments. The preferred course of action in predict-then-act assessments is the one that performs "best" given some (typically small) set of assumptions about the likelihood of various futures and the landscape processes that will be sustained if these assumptions prove true. Such assessments are strongly tied to the validity of their assumptions. These approaches are fraught with challenges, especially when applied over the spatial and temporal extents at which important long-term environmental processes operate and when the ecosystem services that people rely on are taken into consideration (Holling 2001). In contrast, *the explore-then-test* approach seeks actions that are shown to perform well, i.e., are robust across a large number of plausible future alternatives. We define robust decisions as those that result in resilient system behaviors more likely to achieve outcome goals under a variety of possible future trajectories, where aspects of these trajectories are more or less certain. By encompassing a broad range of future possibilities and uncertainties, e.g., local manifestations of climate change, these approaches offer greater potential to be responsive to opportunities and adaptive to problems. By virtue of their exploration of broad sets of contingencies, they also have the potential to serve as constructive means for forging consensus among diverse groups of citizens and policy makers (van Notten et al. 2005; Lempert et al. 2003).

Also important in decision making is the analysis of the tradeoffs among alternative courses of action and the need to address uncertainty (Ullman 2006). Multi-criteria assessment (MCA) methods are oriented to the multi-dimensional character of many natural resource management problems (Hajkowicz 2007: Kiker et al. 2005). They are designed to overcome the problems of multiple objectives, incompatible units, the need to consider both qualitative and quantitative data, and the need to incorporate stakeholder knowledge and preferences (Chee 2004). These tools are inherently capable of integrating biological, social and economic data, and are ideal for assisting evaluation in data-poor situations.

Envision employs the use of Monte-Carlo simulation, using statistical descriptors of decision processes and, optionally, scenario-specific statistical descriptors of model inputs, to allow a given scenario to be run multiple times to produce a distribution of possible outcomes. This approach, coupled with a multi-criteria assessment reflecting user-specified weighting of importance of various ecosystem services, is well suited to the explore-then-test paradigm we will emphasize in the decision platform. Further, this approach allows the assessment of landscape vulnerabilty, i.e. the likelihood of variant or invariant landscape properties to exist under multiple scenario instantiations and multiple policy sets, another useful aspect of uncertainty analysis.

8. Scenarios and Client/Stakeholder Engagement

One key element of the project is client and stakeholder involvement. Continuing dialogue with clients and stakeholders will be necessary in all phases of the project. Early on it will be critical to identify other partners and stakeholders in the WRB who are conducting research and collecting data so that we can incorporate this information into the planning, execution, and integration phases of the WESP project. Clients and stakeholders also will help formulate the plausible alternative scenarios for examining future change. Because some of the tasks will be phased in over the life of the project, feedback from clients on our early products will help inform activities in later phases of the project. In latter stages of the project, client feedback will be essential to ensure the utility of the products provided to the client.

We have a significant history of engaging stakeholder in Willamette issues relevant to ESRP and WESP, dating back to the PNW-ERC effort and continuing through a variety of projects. We feel that provides a very good initial starting point. That said, we understand the need for continued stakeholder engagement for WESP. However, we feel it is important to have an initial set of models and prototype decision support platform in hand before further engaging stakeholders, and therefore that is our initial focus. Additionally, we are pursuing developing a stakeholder strategy using an additional SGE who will be on board Summer 2010. In early outcome of that effort will be a refined, targeted stakeholder engagement plan. We will update the IP when that plan is finalized (expected Fall 2010.) We are aware of a number of similar conversations related to ecosystem service assessments in the Willamette Valley (e.g. the Willamette Partnership's activities towards establishing an ecosystem services marketplace) and will partner with these ongoing efforts where possible to avoid duplication of efforts and maximally leverage WESP resources and capabilities.

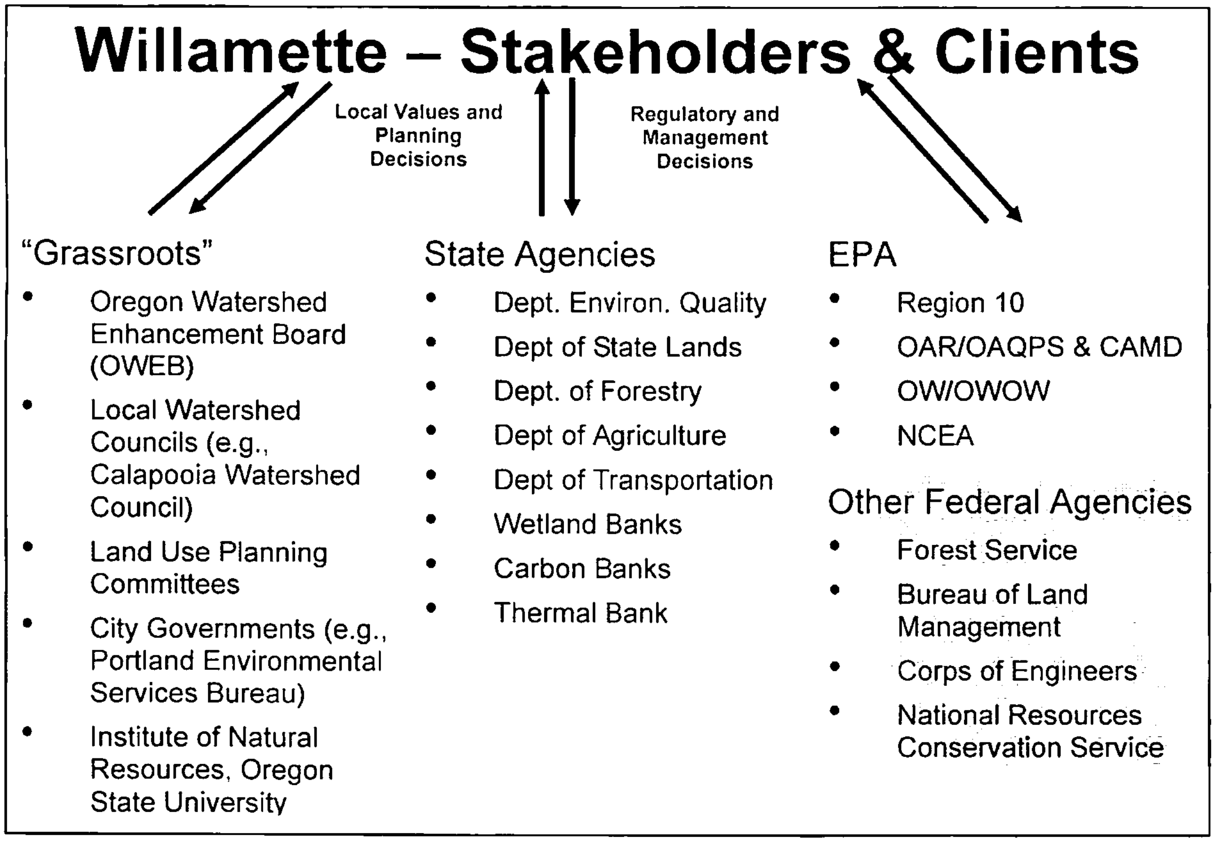


Figure 13. Potential WESP Stakeholders and Clients

The Willamette basin has numerous active client and stakeholder groups interested in ecosystem service assessments (**Figure 13**). We have initiated meetings with many of these groups, and will continue to do so as the WESP activities proceed. The goal of these meetings will be to engage clients and stakeholders in identifying ecosystem services most relevant to their decision needs, determining stressors and drivers their decision processes focus on, and assessing the utility of various approaches to representing future landscape trajectories, decision processes, and ecosystem service productions.

In ESRP, the Decision Support Framework group plans to implement a comprehensive approach to decision-making in the context of ecosystem services. Their work plans to provide formal methods for soliciting problem and value statements, and tools for decision analysis of model results.

9. Management Plan

The project will be managed by a core team of WESP researchers located at the Corvallis WED lab, with collaborative efforts extended to related efforts both within and outside of EPA. In particular, we will maintain linkages with related efforts, particularly the ESRP Nitrogen project, with the goal of developing products and approaches relevant to both efforts.

The uncertainties associated with implementing a project of this scope will require periodic internal and external review to ensure the quality, relevance, and timeliness of the products. Toward that end, we will conduct an external project peer-review in 2011 and at two year intervals thereafter to ensure that the project moves forward in a scientifically defensible way.

WESP will be supported by a Quality Assurance Project Plan (QAPP) that complies with WED requirements. The QAPP will address essential Quality Assurance/Quality Control (QA/QC) elements: (a) QA/QC and research responsibilities, (b) communications, and (c) document control. It will discuss the importance of standard protocols, especially Standard Operating Procedures (SOPs) for experimental data collection. Documenting research conducted under in WESP will occur as described in the QAPP and SOPs. Records will be retained according Appendix D of the NHEERL Quality Management Plan. The research will primarily fall under Categories 3 and 4:

"Category 3: Demonstration or proof of concept projects; method validation studies.

Category 4: Basic, exploratory, conceptual research to study basic phenomena or issues. Includes the characterization of health or ecological mechanisms and/or endpoints in order to improve the understanding of the interaction of environmental compounds, conditions, or processes with human and other life forms: and also includes development of assays or methods for detecting or estimating the influence of a particular environmental agent on a specified health or ecological endpoint."

Category 3 and 4 are considered "503" research with a 20 year period for retaining records. However, some studies may be high enough profile to be Category 2 research.

Deliverables and WESP Annual Performance Measures

The following table (**Table 2**) lists the Annual Performance Measures (APM) for the associated multiyear plan (MYP) for this project. Following, we summarize the task structure proposed to accomplish these performance measures.

Year	MYP	APM	Title
2010	Eco	368	Implementation Plan Based on Conceptual Plan for WESP
2011	Eco	196	Documentation of Key Models to Be Used to Assess Ecosystem Services
2012	Eco	116	Demonstrate/Assess Prototype Decision Support Tool that Integrates Ecosystem Services in WRB
2014	Eco	117	Assessment Report on Multiple Ecosystem Services, Including Tradeoffs Among Services
2014	Eco	61	Report on Decision Framework to Evaluate Effects of Climate Changes on Ecosystem Services and Water Quality in the WRB

Table 2. WESP Annual Performance Measures

Task Structure

Implementation of the project initially will be divided into seven tasks described previously and summarized below in **Table 3**. Each task contributes to several of the APM's outlined in Table 2. On the following pages we provide an initial description of each task, some of which will include efforts by scientists from other laboratories or divisions of ORD outside of WED. Given the uncertainties and the evolutionary nature of the project, it is not possible at this time to predict the ultimate scope of each task; rather, we provide a short narrative outline of the activities that we anticipate will be central to the completion of each task, including the individuals responsible for leading each task. Additional tasks may be identified as the project develops in coming years.

Task # & Activity	Activities Summary
1. Biological Greenhouse Gas Regulation (Co-Leads: Don Phillips, Bob McKane)	**Goals:** 1, 2, 3, 5, 6 **Products:** Improved models of carbon stores and fluxes: manuscript on scenario results and implications for management.
	Determine stocks and fluxes of carbon dioxide equivalents by land use/land cover class for representative units.
	Establish theoretical maxima for greenhouse gas regulation by land use/land cover class based on historical conditions or model projections. Determine the degree of reduction caused by stressors and policy drivers by comparing current conditions with maxima.
	Quantify the responses of greenhouse gas regulation to a set of stressors and policy drivers common across the project in order to contribute to the trade-off analysis among ecosystem services
	Determine the effects of climate change mitigation strategies [e.g. carbon offset forestry and/or biofuels production] on greenhouse gas regulation in conjunction with

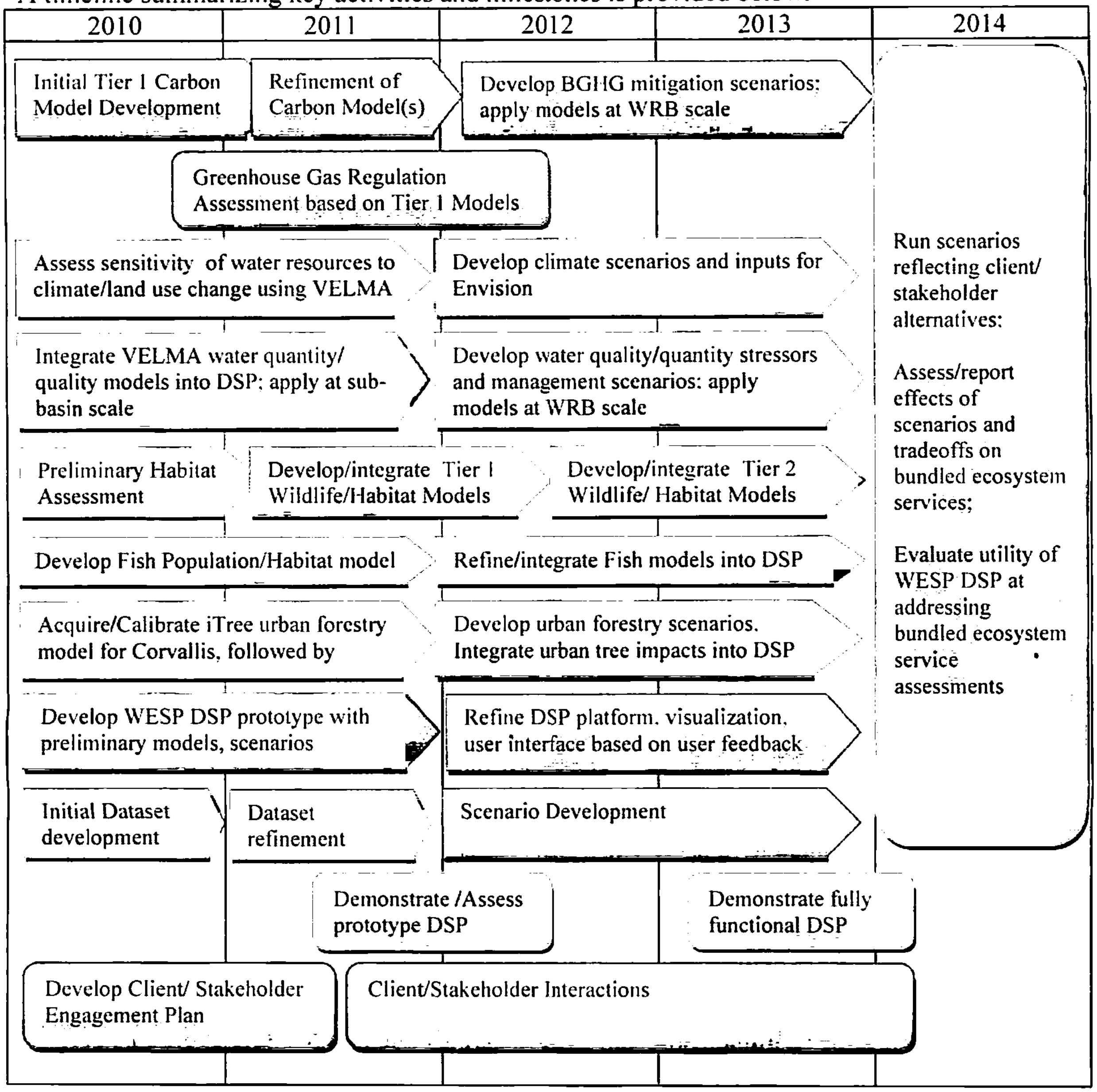
	the other ecosystem services and assess trade-offs among ecosystem services.
2. Water Quality and Quantity Regulation (Lead: Bob McKane)	**Goals:** 1, 2, 3, 5, 6 **Products:** Improved models of water quality and quantity in the WRB; manuscripts on application of Velma within study areas, ecosystem service tradeoffs
	Establish the sensitivity of water resources to climate change and land use by relating historical land use and climate patterns [temperature and precipitation] to stream flows, temperature, sediment and nutrient concentrations.
	Evaluate the potential effects of enhanced carbon sequestration in forests and agriculture, and biofuel production on water resources by using future land use scenarios and evaluating hydrologic responses.
	Using future climate scenarios and hydrological models parameterized for the WRB determine the sensitivity of water resources to climate change.
	Quantify the responses of ecosystem services supporting water resources to a set of stressors and policy drivers common across the project in order to contribute to the trade-off analysis among ecosystem services.
3. Wildlife Populations and Habitat (Lead: Nathan Schumaker)	**Goals:** 1, 2, 3, 5, 6 **Products:** Improved models of wildlife population and habitat; manuscript on reduced-form model and outcomes.
	Provide a preliminary assessment of current habitat condition for one or more key wildlife populations.
	Obtain and evaluate alternative future scenarios for WRB habitat conditions from project collaborators. Produce maps of population viability for the alternative future scenarios to facilitate an assessment of tradeoffs among services in the WRB.
	Contribute to status report on the feasibility of providing a valuation of wildlife and habitat services within the WRB for comparison among the services of interest
	Contribute to report on the effects of climate change and other stresses on changes in habitat condition and biodiversity within the WRB as part of context of bundled ecosystem services.
4. Fish Populations and Habitat (Lead: Denis White)	**Goals:** 1, 2, 3, 5, 6 **Products:** a new model of fish migration and population dynamics for the WRB: manuscript document model, application in WRB.
	Develop a plug-in for *Envision* based on the Rashleigh model for the coarse scale Willamette network using four to five species including one salmonid, one introduced species, and two to three others.
	Develop improved model for seasonal time steps, improved detail for the Willamette network, more species, and better data and models for the processes of habitat selection, interspecies interactions, and fish movement.
5. Air Quality Regulation (Lead: Don Phillips)	**Goals:** 1, 2, 3, 5, 6 **Products:** iTree calibrated for at least one WRB jurisdiction; manuscript reflecting analyses
	Apply i-Tree Eco to assess the removal of air pollutants by trees within the Corvallis Urban Growth Boundary, and economic valuation of these benefits
	Apply i-Tree Vue to assess the removal of air pollutants by trees throughout the WRB, and economic valuation of these benefits.
	Apply i-Tree to assess changes in air pollutant removals due to changes in forest cover and structure under several alternative future scenarios (e.g., climate change, forest management for C offsets).

6. Decision Platform (Lead: John Bolte)	**Goals:** 1, 3, 4, 7 **Products:** A robust decision support platform supporting ecosystem service assessments relevant to WRB stakeholder and clients; manuscript describing platform application in WRB, bundled analyses.
	Develop baseline datasets; generate maps and related representations of current and projected future ecosystems services under plausible alternative future scenarios.
	Demonstrate a prototype decision tool for assessing ecosystem services trajectories and distributions supporting client decision needs.
	Determine the effects of alternative management strategies and policies on current and future ecosystem service provision and assess trade-offs among ecosystem services.
7. Stakeholder/ Client Engagement	**Goals:** 1, 2, 3, 4, 7, 8 **Products:** Stakeholder/Client engagement using WESP tools to better inform decision-making
	Develop a stakeholder/client engagement plan, identifying key stakeholders, and engagement strategy, timeline, and anticipated outcomes.

Table 3. Summary of WESP Tasks

Timeline:

A timeline summarizing key activities and milestones is provided below.



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11. Appendices

Appendix 1. Datasets available for WESP

Category	Dataset Description	Source/Desc	Data Format	Resolution/ Scale	Download Site/Contact
ANTHROPOGENIC					
Agriculture	Cropland Data Layer	USDA/National Agricultural Statistics Service	grid	30 m	http://datagateway.nrcs.usda.gov/
Census	Population 2000 Blockgroup	Bureau of the Census	polygon		http://geogateway.epa.gov/Portal/
	Population 1990 Blockgroup	Bureau of the Census	polygon		
	Population 1970 Census County Divisions	Bureau of the Census	polygon		http://www.fsl.orst.edu/pnwerc/wrb/access.html
	Population 1930 Minor Civil Divisions	Bureau of the Census	polygon		http://www.fsl.orst.edu/pnwerc/wrb/access.html
	Dwelling Units 1850	Compiled by Institute for a Sustainable Environment - University of Oregon	point		http://www.fsl.orst.edu/pnwerc/wrb/access.html
Transportation	Streets	Tele Atlas North America (TANA)	line	various	http://geogateway.epa.gov/Portal/
	Railroad	Tele Atlas North America (TANA)	line	1:100,000	http://geogateway.epa.gov/Portal/
Ownership	Land Ownership	Compiled by Institute for a Sustainable Environment - University of Oregon from BLM Surface Management Status maps	polygon		http://www.fsl.orst.edu/pnwerc/wrb/access.html
	City limits and city annexations for the State of Oregon 1996, 1999, 2003, 2005, 2006, 2007	Oregon Department of Transportation	polygon	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
	Urban Growth Boundaries	Oregon Department of Transportation and Dept. of Land	polygon	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml

		Conservation and Development			
	Forest Ownership, West Oregon	Oregon State Forestry Science Lab	polygon	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
GEOPHYSICAL					
Climate	Precipitation, Max. Temp.\Min. Temp.\Dew Point - Annual	PRISM Group	grid	4 km	http://www.prism.oregonstate.edu/products/matrix.phtml
	Precipitation, Max. Temp.\Min. Temp.\Dew Point - Monthly	PRISM Group	grid	4 km	http://www.prism.oregonstate.edu/products/matrix.phtml
Elevation	National Elevation Dataset 10 Meter	USGS	grid	10 m	http://seamless.usgs.gov/website/seamless/viewer.htm
	National Elevation Dataset 30 Meter	USGS	grid	30 m	http://seamless.usgs.gov/website/seamless/viewer.htm
	Shuttle Radar Topography Mission (SRTM) 30 Meter	NASA/USGS	grid	30 m	http://seamless.usgs.gov/website/seamless/viewer.htm
Ecoregions	Bailey Domains, Divisions, Provinces and Sections	USDA Forest Service	polygon		http://www.fs.fed.us/rm/analytics/publications/eco_download.html
	Omernik Level 3 and Level 4	USEPA	polygon		http://www.epa.gov/wed/pages/ecoregions.htm
Geology	Major Bedrock Lithologic Units for Pacific Northwest	USGS	polygon	1:500,000	http://www.fsl.orst.edu/pnwerc/wrb/access.html
	Geologic Map of Oregon including faults	USGS	polygon	1:500.000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
Hydrology	NHDPlus	USEPA/USGS	polygon, line, point, grids	1:100,000/30 m	http://horizon-systems.com/NHDPlus/index.php
	Rivers and Streams	Pacific Northwest Hydrography Framework	vector	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
	Waterbodies	Pacific Northwest Hydrography Framework	vector	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
	Hydrologic Units - 1st through 6th Field	Oregon BLM-USFS	polygon	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
	8-Digit Hydrologic Units (HUC)	USGS	polygon	1:250,000	http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml
	12-Digit Watershed		polygon	1:24,000	

	Boundary Dataset				
	Subwatersheds (SWAT/AGWA)	USEPA	polygon		William Kepner/USEPA/Landscape Ecology Branch
	Willamette River Active Channel Timesteps (1850, 1895, 1932, 1995)	Oregon State University - Stan Gregory	polygon		http://www.fsl.orst.edu/pnwerc/wrb/access.html
	1996 Willamette River Flood	unknown	polygon		http://www.fsl.orst.edu/pnwerc/wrb/access.html
	1999 Willamette River Revetments between Eugene and Portland	Oregon State University/Dept. of Fisheries Wildlife - Linda Ashkenas	vector	1:24,000	http://www.fsl.orst.edu/pnwerc/wrb/access.html
	Dams		point	1:24,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
Soil	Statsgo	NRCS	polygon		http://soils.usda.gov/survey/geography/statsgo/
	Ssurgo	NRCS	polygon		http://soils.usda.gov/survey/geography/ssurgo/index.html
	WED field data (very small portion of WRB in forests)				
BIOLOGICAL					
Landcover	1851 Veg	Derived from surveys by the General Land Office			http://www.fsl.orst.edu/pnwerc/wrb/access.html
	1938 Vegetation	Oregon Natural Heritage Program	polygon	1:100,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
	NLCD 1992	Multi-Resolution Land Characteristics Consortium (MRLC)	grid	30m	http://seamless.usgs.gov/website/seamless/viewer.htm
	NLCD 2001	Multi-Resolution Land Characteristics Consortium (MRLC)	grid	30 m	http://seamless.usgs.gov/website/seamless/viewer.htm
	Imperviousness 2001	Multi-Resolution Land Characteristics Consortium (MRLC)	grid	30m	http://seamless.usgs.gov/website/seamless/viewer.htm
	GAP (1999)	Oregon Gap Analysis Program	polygon	1:100,000	http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
	GAP (2004)				
	Coastal Change Analysis Program (C-CAP) 1996	NOAA	grid	30 m	http://www.csc.noaa.gov/crs/lca/ccap.html
	Coastal Change Analysis Program (C-CAP) 2001	NOAA	grid	30m	http://www.csc.noaa.gov/crs/lca/ccap.html

	Willamette Valley Land Use / Land Cover (1993)	Oregon Dept. of Fish and Wildlife	polygon	1:24,000	http://www.nwhi.org/index/gisdata
	Landuse and Landcover ca. 1990 - Willamette River Basin	University of Oregon, Institute for a Sustainable Environment	grid	25 m	http://www.fsl.orst.edu/pnwerc/wrb/access.html
	Landuse and Landcover ca. 2000 - Valley Ecoregion of the Willamette River Basin	University of Oregon, Institute for a Sustainable Environment	grid		http://www.fsl.orst.edu/pnwerc/wrb/access.html
Forest	Pacific States Forest Vegetation Mapping	Gradient Nearest Neighbor (GNN) Pacific States	grid	30 m	http://www.fsl.orst.edu/lemma/gnnpac/spatialDatabases.php
	Tree Canopy Cover 2001	National Land Cover Dataset	grid	30 m	http://seamless.usgs.gov/website/seamless/viewer.htm
	National Biomass and Carbon Dataset 2000	Woods Hole Research Center	grid	30 m	http://www.whrc.org/nbcd/
Wetlands	National Wetlands Inventory	US Fish and Wildlife	polygon	1:24,000	http://wetlandsfws.er.usgs.gov/NWI/
	Willamette Valley Natural Wetlands	Oregon Natural Heritage Program	polygon		http://www.oregon.gov/DAS/EISPD/GEO/alphalist.shtml
IMAGERY	Digital Raster Graphics	USGS			http://seamless.usgs.gov/website/seamless/viewer.htm
	Digital Orthophoto Quadrangles	USGS			http://seamless.usgs.gov/website/seamless/viewer.htm
	National Agriculture Imagery Program (NAIP)	USDA			http://seamless.usgs.gov/website/seamless/viewer.htm
REFERENCE					
Map Indexes	Quadrangle Index 1:24,000	USGS			
	Quadrangle Index 1:100,000	USGS			
Government Units	Counties		polygon		
	States		polygon		
Other	Geographic Names Information Systems	USGS	point		http://geonames.usgs.gov/domestic/download_data.htm
	Study Area Boundary	University of Oregon, Institute for a Sustainable	polygon	1:24,000	http://www.fsl.orst.edu/pnwerc/wrb/access.html

		Environment			
FUTURE SCENARIOS					
	Plan Trend 2000 - 2050: 10 year increments	Pacific Northwest Ecosystem Research Consortium	grid	30 m	http://www.fsl.orst.edu/lemma/gnnpac/spatialDatabases.php
	Development 2000 - 2050: 10 year increments	Pacific Northwest Ecosystem Research Consortium	grid	30 m	http://www.fsl.orst.edu/lemma/gnnpac/spatialDatabases.php
	Conservation 2000 - 2050: 10 year increments	Pacific Northwest Ecosystem Research Consortium	grid	30 m	http://www.fsl.orst.edu/lemma/gnnpac/spatialDatabases.php
	Conservation Restoration Opportunities 2000 - 2050: 10 year increments	Pacific Northwest Ecosystem Research Consortium	grid	30 m	http://www.fsl.orst.edu/lemma/gnnpac/spatialDatabases.php

Appendix 2. Summary of Ecosystem Services of Interest to WESP.

Ecosystem Service	*Climate Regulation*	*Air Quality Regulation*	*Disturbance & Natural Hazard Regulation: Fire & Flood*	*Water Quality Regulation*	*Water Quantity Regulation*	*Food & Fiber Production*	*Biodiversity (plants, fish & wildlife)*
Ecosystem Structure & Function	Carbon sequestration; Production of other GHGs; Shading	Air pollutant regulation	Ecosystem spatial and temporal characteristics	Nutrient and sediment regulation	Surface, subsurface, & ground water flows	Primary production	Habitat
Human Benefit	Avoided health hazards to and dislocations of people	Avoided health hazards	Avoided hazards to health and property from fires and floods	Quality water for drinking, swimming, and fishing; avoided health hazards	Supplies of water for drinking, irrigation, recreation; Control of flooding	Sustenance and shelter	Amenities and recreation
Land Use Category							
Large River Riparian Wetlands	Long-term storage of C in vegetation & soils: ($Mg\ ha^{-1}\ y^{-1}$); N_2O production ($Mg\ ha^{-1}\ y^{-1}$)	Minimal	Frequency and magnitude of flood events (#, magnitude, duration of flows ≥ bank-full)	N, P, DOC, meth Hg, TOC, TSS ($kg\ ha^{-1}\ y^{-1}$); Specific Cond. ($\mu S\ cm^{-1}$); Temperature regulation (°C)	River flow $m^3 d^{-1}$; Frequency, extent & duration of inundation per year, extent of hyporheic flow	Tree standing crop ($m^3\ ha^{-1}$)	Bank-full area & duration; area in different vegetation age classes; Aquatic connectivity; Plant species density (# ha^{-1})
Agriculture	Soil C accumulation or loss by ag type or practice ($g\ m^{-2}\ y^{-1}$); Soil C quality ($Mg\ ha^{-1}$ in a given pool type); N_2O production ($Mg\ ha^{-1}\ y^{-1}$)	Minimal (Particulate matter from field burning , but tightly regulated); Ammonia deposition . associated with fertilizer and animal feedlots ($kg\ N\ ha^{-1}\ y^{-1}$)	Minimal	Hydrologic N & P flux ($kg\ ha^{-1}\ y^{-1}$) by basin or pixel; N removal by crops, wetlands (%, $kg\ ha^{-1}\ y^{-1}$); Spatial configuration of wetlands; Riparian shade for stream temperature regulation (°C)	CFS from streams in basin, monthly; average depth to water table by model cell or "pixel" as a function	ha, $Mg\ ha^{-1}\ y^{-2}$, and $\$\ y^{-1}$ by crop type; Hybrid poplar (ha, $m^3\ ha^{-1}\ y^{-1}$, $\$\ y^{-1}$)	Vegetation cover in wetlands; Wetland type in some areas; Fish population model estimates (species distribution, presence/absence)

Appendix 2. Summary of Ecosystem Services of Interest to WESP.

Ecosystem Service	*Climate Regulation*	*Air Quality Regulation*	*Disturbance & Natural Hazard Regulation: Fire & Flood*	*Water Quality Regulation*	*Water Quantity Regulation*	*Food & Fiber Production*	*Biodiversity (plants, fish & wildlife)*
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Human Benefit	Avoided health hazards to and dislocations of people	Avoided health hazards	Avoided hazards to health and property from fires and floods	Quality water for drinking, swimming, and fishing; avoided health hazards	Supplies of water for drinking, irrigation, recreation; Control of flooding	Sustenance and shelter	Amenities and recreation
Land Use Category							
Large River Riparian Wetlands	Long-term storage of C in vegetation & soils: (Mg ha^{-1} y^{-1}); N_2O production (Mg ha^{-1} y^{-1})	Minimal	Frequency and magnitude of flood events (#, magnitude, duration of flows ≥ bank-full)	N, P, DOC, meth Hg, TOC, TSS (kg ha^{-1} y^{-1}); Specific Cond. (μS cm^{-1}); Temperature regulation (°C)	River flow m^{3}d^{-1}; Frequency, extent & duration of inundation per year, extent of hyporheic flow	Tree standing crop (m^3 ha^{-1})	Bank-full area & duration; area in different vegetation age classes; Aquatic connectivity; Plant species density (# ha^{-1})
Agriculture	Soil C accumulation or loss by ag type or practice (g m^{-2} y^{-1}); Soil C quality (Mg ha^{-1} in a given pool type); N_2O production (Mg ha^{-1} y^{-1})	Minimal (Particulate matter from field burning , but tightly regulated); Ammonia deposition associated with fertilizer and animal feedlots (kg N ha^{-1} y^{-1})	Minimal	Hydrologic N & P flux (kg ha^{-1} y^{-1}) by basin or pixel; N removal by crops, wetlands (%, kg ha^{-1} y^{-1}); Spatial configuration of wetlands; Riparian shade for stream temperature regulation (°C)	CFS from streams in basin, monthly; average depth to water table by model cell or "pixel" as a function	ha, Mg ha^{-1} y^{-2}, and \$ y^{-1} by crop type; Hybrid poplar (ha, m^3 ha^{-1} y^{-1}, \$ y^{-1})	Vegetation cover in wetlands; Wetland type in some areas; Fish population model estimates (species distribution, presence/absence)

Forest	Accumulation, loss, and storage of C in vegetation & soils (Mg ha^{-1} y^{-1})	NO_2 removal (g m^{-2} y^{-1})	Frequency & magnitude of fire events (burned ha y^{-1})	Reduction of nutrients and sediments (kg ha^{-1} y^{-1})	Primary source of regional groundwater recharge and discharge (m^3 d^{-1}); Moderation of peak runoff and low summer flows (m^3 d^{-1})	Fiber, pulp and biofuel (m^3 ha^{-1} y^{-1})	Number of species & population densities of aquatic and terrestrial animal species (population density, # ha^{-1})
Urban	Accumulation, loss, and storage of C in urban trees (Mg ha^{-1} y^{-1}); \$ y^{-1} of energy savings; CO_2 emissions avoided (Mg y^{-1})	O_3, NO_2, SO_2, CO, PM removal (g m^{-2} canopy area y^{-1}, Mg y^{-1})	Minimal	N, P, metals in stormwater runoff (g m^{-3})	stormwater runoff (m^3 d^{-1})	Minimal	Minimal

Revised Figure 2 showing simple links between Nr, services and well-being.